GEOPHYSICAL INSTITUTE

of the

UNIVERSITY OF ALASKA

ANALYSIS OF AURORAL DATA FROM NASA'S 1968 AND 1969 AIRBORNE AURORAL EXPEDITION

SEMI-ANNUAL REPORT

Grant No. NGR 02-001-099
Suppl. No. 1

(NASA-CR-135497) ANALYSIS OF AURORAL DATA FROM NASA'S 1968 AND 1969 AIRBORNE AURORAL EXPEDITION Semiannual Report (Alaska Univ., College.) ~~94~~ 95 p HC $6.75 CSCL 04A G3/13

N73-32278

Unclas
15582

June 1973

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER

Semi-Annual Status Report on Research Conducted under NASA/AMES Research Grant # NGR-02-001-099, Suppl. No. 1

ABSTRACT

The main objectives of the project, funded under NASA/AMES Research Grant #NGR-02-001-009, are methodical compilation, reduction and correlated analysis of spectrophotometric data obtained by various scientific groups during NASA's 1968 and 1969 Airborne Auroral Expedition. To this date the following tasks, aimed at fulfilling some of these objectives, have been completed:

1. Various spectrophotometric and all-sky camera measurements made by different University and Research Laboratory groups during the 1968 and 1969 Airborne Auroral Expeditions have been gathered at one location (the Geophysical Institute of the University of Alaska), previewed and arranged for quick retrieval and analysis.

2. Meetings of various principal investigators involved in NASA's Airborne Auroral Expeditions were held in Baltimore and in Colorado to establish scientific objectives, of the proposed correlated analysis of various data, acceptable to all groups contributing data for this project.

3. Detailed analysis of all-sky camera pictures have been made to identify periods when auroras covered the full field of view of all detectors from which data, for correlated analysis, were obtained. The type and morphology of such auroras have also been identified.

4. Preliminary sorting of data sections suitable for correlated analysis has been made.

5. Development of a system for data reduction, involving preliminary checks, calibration and interfacing of various equipments, has been successfully completed.

6. Special electronic circuits, required to accomodate different data sets in the analysis system and to compensate for differences between recording systems employed by various investigators and the playback and recording system available for analysis, have been developed, constructed and interfaced with the data processing system.

7. An active filter amplifier has been built to retrieve very low level signals from the mid-day auroral measurements.

8. The contents of the spectrometer channel from all magnetic tapes used by LASP (University of Colorado) during flights # 2, 3, 4, 5, 12 and 13, in 1969, have been played back on paper charts to identify exact instances when changes in scan period, resolution and wavelength region monitored were made, as well as to compile a detailed log of the data that can be used for averaging and analysis.

9. A system for selective digitization of the auroral optical data and the software for digital processing of these data, including CALCOMP plot out, have been developed.

10. Individual as well as averaged spectra have been obtained from flight #21 (1969) and flights # 2, 3, 4, 5, 12 and 13 (1969); absolute intensities of various auroral features have been established.

11. Photometer measurements of OI(6300A) red line obtained on the Ferry flights in 1969 have been analyzed to identify possible signature for the electron trough.

12. Satellite particle data have been used to compute energies of the electrons in the loss cone and compared with energies of the electrons precipitated in the auroras as inferred from the brightness of the N_2^+ 1NG bands.

13. Vibrational distribution of N_2^+ 1NG bands in mid-day auroras has been obtained and compared with corresponding data from night-time auroras.

PRECEDING PAGE BLANK NOT FILMED

INTRODUCTION

Early in 1968 and again towards the end of 1969, NASA sponsored a total of forty two flights in mid- and high latitude-areas specifically for studying atmospheric emissions from the nightglow and the aurorae, as well as events related to magnetic substorms. Several universities and national as well as industrial research laboratories participated in these missions, employing a sophisticated array of photometers, spectrometers, all-sky cameras, TV cameras, radiometers, riometers and magnetometers to monitor various high altitude atmospheric phenomena. Most of these groups reduced and analyzed their own data and published their results in the papers and reports listed in the reference section (ref. #1 to 29) of this report. However very little, if any, joint analysis of the various data sets was attempted partly because of the large number of groups involved and the problems associated with geographic separation of these groups which hampered frequent contacts and consultations. Yet it was generally felt by most of the participants of the two airborne expeditions that a correlated analysis of measurements made by various groups would yield scientifically interesting results.

To accomplish such a coordinated study the aeronomy group at the Geophysical Institute of the University of Alaska offered, in October 1972, to undertake the compilation, organization and analysis of the massive wealth of data, obtained by various scientists from the two airborne expeditions. In a proposal submitted to NASA/AMES it was suggested that such a project should initially involve only the measurements made by LASP of the University of Colorado, the Johns Hopkins University, the Lockheed Research Laboratories and the Geophysical Institute of the University of Alaska.

It was further proposed that the project be streched over two years with most of the first year devoted to centralizing, previewing and partially analyzing the data of these groups while major reduction and extensive analysis of all the data could be worked on during the second year. In addition it was suggested that a meeting, of all participants of the two airborne expeditions, be convened during the second year, to discuss the results of the analysis, and if the scientists involved considered it worthwhile to seek an extension of the project for further analysis of data including those from groups not initially covered in this project. These proposals were approved by NASA/AMES and funds for the preliminary work were made available in January 1973. This semi-annual status report describes some of the work that has been done in the first 6 months of the first year and the scientific results that have been obtained from some of the analyses. It must be stressed here that this is only a preliminary report and some refinement, or even changes, may be made in the spectra and absolute intensities of auroral emissions, as the data is analyzed in greater detail.

Scientific Objectives of the Project

Meetings of some of the principal investigators who participated in both the 1968 and 1969 Airborne Expeditions were held in Baltimore and in Boulder to discuss specific problems in auroral physics which can be tackled through the analysis of the spectrophotometric data gathered by various group during the two airborne expeditions. Dr. R. H. Eather, Dr. K. A. Dick, Dr. M. H. Rees, Professor W. G. Fastie and a representative from the Geophysical Institute participated in these discussions. It was generally agreed at these meetings that it would be scientifically worthwhile to analyze the data with a view to obtaining detailed auroral spectra in the UV to IR range from different auroras, as well as the absolute intensities of various auroral features in these spectra, and to study any differences in the spectra which might show up. For example simultaneous spectra recorded by various spectrometers during break-up auroras could be compared with corresponding measurements from rayed auroras, polar-cap auroras and mid-day auroras, in an attempt to observe any differences in the relative intensities of various emission features and if possible to try to relate these differences to changes in the characteristic energies of the precipitating particles. It was further agreed that such analysis should be limited to measurements obtained during the periods when auroras covered the full field of view of all detectors from which data for the proposed analysis were obtained. The need to invest relatively more efforts in analyzing the spectra of the optical emissions in the mid-day auroras, was clearly recognized since to that date relatively little work had been done on such auroras.

General Nature of Data

Following the meetings in Baltimore and in Boulder the following organizations forwarded various data sets to the Geophysical Institute.

1. LASP - University of Colorado: This group employed a half meter Ebert spectrophotometer both in 1968 and 1969 Airborne Expeditions and monitored auroral emissions from the N_2^+ 1NG, N_2 2PG and N_2 VK bands and line emission from atomic nitrogen, mostly in the 3000 to 4000A region. A photometer mounted coaxially with the spectrometer, was used in 1969 to monitor the intensity of N_2^+ 1NG(0-1) band. Only chart records of individual spectra and the sum of various spectra averaged in real-time, are available from the 1968 measurements. Hence it is not feasible to further reduce these data and it is also difficult to derive absolute intensities of various auroral features prominent in various spectra. Still, there is a large number

of detailed spectra in these records and some of the data obtained during strong aurora can be used in conjunction with measurements made by other groups to compile auroral spectra in the UV, visible and near IR. Comparison with photometric measurements made by other scientists may also permit an assesment of the absolute intensities of the auroral features in the 3000 to 4000A region obtained by LASP. In particular, an attempt is being made to compare the spectra, from 3000 to 4000A, obtained by LASP during the intense westward surge under which the aircraft flew during flight # 21 on March 3rd, 1968, with corresponding measurements, in the 2nd, 3rd and 4th order of the 12,000 to 14,000 A region, made by the Johns Hopkins University and various photometer measurements of other investigators.

The 1969 spectrophotometric measurements made by LASP, are recorded on 7 track magnetic tapes. Contents of various channels are as follows:

- Ch. 1: Output of the N_2^+ 1NG(0-1) band photometer
- Ch. 2: Voice
- Ch. 3: Time (1 minute frames)
- Ch. 4: Scan pulse
- Ch. 5: Spectrometer output (100x)
- Ch. 6: Spectrometer output (10X)
- Ch. 7: 1250 cps

Calibration marks of 0 to 5 volts, in one volt steps, are recorded, mostly at the beginning and end, of each tape. A log, giving approximate resolution at which the spectrometer was operated, the wavelength region scanned and the length of scan duration, has been compiled by Dr. M. H. Rees,[25] of LASP. Details relating to spectrometer resolution and sensitivity have also been published.[25] The contents of the magnetic tapes were not dumped on chart records at any time prior to the commencement of the project reported here.

2. Johns Hopkins University: Both during the 1968 and 1969 expeditions the group from Johns Hopkins University operated a one-meter Ebert spectrometer, whose first order linear - dispersion is shown in figure 1, and a multichannel photometer. All the data were recorded on a 7 channel magnetic tapes and on chart records and were partially analyzed in realtime, the latter included averging of various spectra. The following chart lists the contents of the various channels of the magnetic tapes provided by the Johns Hopkins University. Magnetic tapes containing data from the 1968 expedition:

Ch. 1	Synch
Ch. 2	Spectrometer (1X)
Ch. 3	$\frac{1}{10}$Hz square pulses
Ch. 4	—
Ch. 5	Photometer (1X)
Ch. 6	Spectrometer (10X)
Ch. 7	Photometer (10X)
Edge Track	UT (5 minutes/frame)

In 1969 only a few of the channels were used. The linear output from the spectrometer was recorded on channel 7 while the synch pulses are on channel 5 and UT information is contained in the edge track.

In 1968 the spectrometer scanned from 12,000 to 14,000 A and superposed spectra in the 3000-3500A, 4000-4667A and 6000-7000A were recorded, in the 4th, 3rd, and 2nd order, during auroras; order sorting filters were only employed when monitoring the nightglow emission during aurora-free periods. The photometer had the following five channels: N_2 2PG(0-0) band, N_2^+ 1NG(0-0) band, N_2 1PG(5-2) band, OI green line and OI red line. The measurements of N_2 2PG(0-0) band intensity were contaminated by leaks through a secondary bandpass in the filter used to monitor this emission. Magnetic and chart paper records of all data taken on flights # 5 through flight # 27, in 1968, as well as chart records of real time and subsequent extensive reduction of all the data, carried out by Dr. K. A. Dick, have been made available for this project. These include average spectra of both nightglow and auroral emissions from practically every flight made in 1968, absolute intensities of N_2^+ 1NG(0-0) band, N_2 1PG(5-2) band, OI green line and OI red line from almost all flights as well as a complete log of the various modes in which the spectrometer was operated in 1968.[9]

Magnetic tape and chart records of all measurements made in 1969 during flights # 3 to 15 as well as detailed log of these measurements have been provided. During flight # 3 the spectrometer yielded spectra of N_2 2PG and N_2^+ meinel bands while during flights # 4 and 5 the spectrometer was used to monitor the (0-1) and (1-2) bands of N_2^+ 1NG system together with H_β emission at 4862A. For the rest of the flights, in 1969, the spectrometer scanned the wave length range between 6800 and 7000 A, in second order nightglow OH(7-2) band and the auroral emissions from N_2 1PG and N_2^+ Meinel bands. The photometer had 6 channels, five for monitoring (0-1) and (1-2) bands of N_2^+ 1NG, (0-0) band of N_2 2PG and the green and red lines of OI; the sixth channel contained an opque disc to block all the light while monitoring the dark current of the photomultiplier tube. Absoulte intensities of the five emissions have been provided for all auroral flights (#3 through 15) made in 1969.[12]

3. Rice University: Two-minute averages of tilting photometer data on the intensities of N_2^+ 1NG(0-1) band, Hβ and the green and red lines of OI as well as the invariant latitudes and magnetic times corresponding to these measurements have been provided.[13]

4. Lockheed Research Laboratories: Two minutes averages of tilting photometer data on N_2^+ 1NG(0-1) band, O_2^+ 1NG(0-0) band, Hβ, NI line at 5200A and the green and red lines of OI, as well as the corresponding universal time, geographic coordinates, magnetic time, L value, shadow height and ratios of the O_2^+ 1NG(0-0) band, Hβ, NI line and the green and red lines of OI to the N_2^+ 1NG(0-1) band have been provided for all flights made in 1969.[16] In addition data obtained from a three frequency riometer during both the 1968[6] and 1969[7] expeditions have been made available to us. Satellite particle-data taken aboard ATS-5 and OVI-18 during the periods when the aircraft flew either under the path or near the conjugate point of these satellites have also been provided by the Lockheed group.[27]

5. Geophysical Institute of the University of Alaska: 35 mm films of the all-sky camera pictures taken both during the 1968 and the 1969 Airborne expeditions and a log of auroral events photographed as well as an identification of the type of aurora and the substorm phase in progress have been made available in this project [4,5]. In addition data from fixed and meridian scanning photometers flown on these expeditions (to monitor N_2^+ 1NG(0-1) band, Hβ, N II line and green line of OI in 1968 and N_2^+ 1NG(0-1) N_2 1PG(1-0) and (4-1) bands as well as Hβ, NI, NII, OI red and green lines and OH(4-0), (6-3) and (8-4) bands in 1969) together with partial reduction and results from some analysis of portions of these data have been provided.[22,26] Only chart records of the 1968 photometer data are available while the 1969 measurements are stored on magnetic tapes.

6. NASA/AMES Research Center: Copies of auroral spectra, from a half meter spectrometer, in the 3500 to 4300A region, taken by Dr. Gedsden[19] during twelve selected periods in 1968, geomagnetic data recorded by

Dr. Eupher and those from Norwegian geomagnetic observatory, K_p indices for the flight periods, water vapor data recorded by Dr. Kuhn and OH measurements of Dr. Morell, all pertaining to 1969 flights, have been furnished for use in this project.

7. Copies of particle data, from OGO IV and OGO VI taken during those periods when the aircraft flew under conjugate points of the satellite have been made available by Dr. Hoffman of NASA and Dr. Evans of NOAA.

All-sky Camera Pictures

Individual frames of all-sky camera pictures taken both during the 1968 and 1969 expeditions were visually scanned and compared with zenith photometer measurements of Rice University,[13] Lockheed Research Laboratory[16] and Johns Hopkins University.[9,12] It was found that the photometer measurements recorded higher than nightglow level signals even when the all-sky camera pictures showed no auroral arcs or patches within the full field-of-view(fov) of the photometers. The strengths of these signals relative to those recorded when the auroras had moved into the detectors' fov are much higher than the values one would expect from the Rayleigh scattering of the bright auroral forms. Clearly, then, there must be relatively weak but perhaps more diffuse auroral emissions in additions to the prominent arcs, rays and patches recorded by the all-sky cameras. Perhaps the characteristic energies of the more wide-spread particle precipitations that give rise to the diffuse glow are different from those of the particles responsible for the more localized and brighter auroral emissions. An analysis of this problem requires detailed comparison of the ratios of various optical emissions in these two types of auroras and this will be undertaken later.

The primary aim of scanning the all-sky camera pictures was to identify periods when the auroras covered the full fov of all detectors pointing in the zenith. Table 1 lists the results of this search, giving the time and length of occurrence as well as the type of aurora involved. The most notable aurora was encountered during flight # 21 (UT 0710-0720) in 1968 when a bright westward traveling surge covered greater part of the sky. Scientifically useful data from the mid-day auroras were obtained between UT 0811 and 0851 during flight # 12 and UT 0650 to 0757 as well as UT 0828 to 0850 during flight # 13, in 1969.

Data Processing System

Most of the spectrophotometric data obtained by LASP, Johns Hopkins University and the Geophysical Institute are stored on magnetic tapes. For playback and analyses of these data, NASA Ames Research Center kindly loaned the Geophysical Institute a PI 200 taperecorder, a CAT-400 Signal Averager and a Beckman thermo-pen chart recorder. Unfortunately the PI 200 tape recorder can only take one inch wide tapes while all the data-tapes are half inch wide. The CAT-400 Signal Averager has only 400 memory channels while the quality of data necessiates the use of at least 1000 memory channels, and often much more. The Beckman chart recorder is a highly sensitive instrument but unfortunately it is fitted with heat-pens which do not produce reasonable traces and the pen deflection is limited to two inches. Hence these three instruments are inadequate for our needs. We have therefore had to rely on the use of a PI 400 tape recorder which will accept half ince tapes. This instrument is part of the Geophysical Institute's Pre-processor system and it is heavily used by various groups thus necessiating working at night in order to secure the services of this instrument. An added problem is one related to the differences in the center frequencies of PI 400 from those used by LASP and Johns Hopkins University in recording their data. This leads to a negative DC offset much larger than that which can be compensated on the chart recorder or a signal averager having a large number of (1024) channels. Since capacitive coupling led to a lot of problems, we built an electronic system to offset the DC level of the output from the tape reproduce system. The synch pulse for each spectrometer scan had to be similarly processed and in addition its rise time had to be sharpened, through the use of Schmidt trigger, to less than one microsecond in order to trigger a signal averager. Problems associated with differencies in the various scan periods used by LASP and the sweep periods available on the signal averager necessiate averaging the scans in two or more sections, but the lack of delay-time electronics in one of the two signals averagers used, obliged us to construct an electronic system for modifying the width of the synch pulse to make it feasible to average different portions of the scans. Additional problems arise from the difference in the DC reference levels used by different groups in recording their data. Hence, while one group's data may come out in -3 to 0 volt range, and can be dealt with using the above electronic system, a second group's data may be reversed going from 0 to -3V. This creates problems in the pulse shaping circuits which will only accept positive pulses. Hence an inverting operational operlifier had to be built to accomodate such signals. All these electronic circuits are shown in Figure 2.

In addition to the tape recorder, we have had to borrow, locally, an Enhancetron Signal Averager (1024 channels) and an X-Y recorder, which uses an ink-pen. The signal attenuation in the Enhancetron is inversely proportional to the sweep period and the trace fidelity on the X-Y recorder is directly proportional to the sweep time. Hence we are obliged to playback the tapes as slowly as possible and to spend several tens of minutes in tracing every output of the signal averager on the X-Y recorder. The result of all this is to slow down the analysis procedure considerably.

Signal averaging improves the quality of the data only in proportion to the square root of the number of repetative scans summed. Since auroral data of interest span only few scans and the signal to noise ratio is low it is necessary to pre-process the data to filter out some noise and amplify the signals before averaging them. This is critically important in reducing the data from the mid auroras where short-lived, weak emissions produce only a limited number of useful scans with very low signal to noise ratio. Ordinary R-C filters not only attenuate the signal but they also alter the line shapes and smear out adjacent individual signals. We have therefore built an active filter amplifier of variable cut-off frequency, shown in Figure 2, and interfaced it with the output of the reproduce system of the PI 400 tape recorder.

<u>Digital Processing System</u>

A system for A to D conversion of auroral optical data has been set up. The sampling rate is adjustable to provide 4095 bytes for every spectrometer scan. A to D conversion can be performed either continuously or in steps. In the latter case the synch pulse is used to actuate the digitization system and either the rising or the falling edge of the synch pulse can be used to define the starting point of each scan. This scheme permits selective digitization and is highly economical in digitization time, in length of digital magnetic tapes used, in memory required to process the digital data, in CPU time and in the complexity of the software. Savings result from eliminating the need for digitizing the synch-pulse channel.

Computer programs for digital analyses of the auroral data, on IBM 360/40, as well as for graphical display, on CALCOMP, have been developed. Figure 3 shows the result of digitizing six scans, from the 1/2 meter spectrometer, recorded between UT 0554 and 0557 during flight #3 in 1969, summing them in IBM 360/40 and plotting the end product on a CALCOMP. A single scan from the one meter spectrometer, recorded around UT 0715 during flight #21 in 1968, which was digitized, processed on IBM 360/40 and plotted on a CALCOMP, is shown in figure 4.

<u>Spectra of Auroral Optical Emissions</u>

So far we have reduced the data, from Johns Hopkins University's one meter and University of Colorado's (LASP) half meter Ebert-spectrometers, taken during flight # 21 in 1968 and flight # 3, 4, 12 and 13 in 1969. Since no chart records of the output from the half meter spectrometer were available we have played back the time, synch pulse and spectrometer (100X) channels of the magnetic tapes containing the 1969 data from flights # 3, 4, 12 and 13. In addition, whenever any of the optical emission recorded on the 100X channel was found to be saturated the corresponding portions of the 10-fold amplified output of the half meter spectrometer were played back. From the chart records of these playbacks we have compiled a detailed log of the exact times when changes in the spectrometer's slit width, scan period and wavelength range (covered in a scan) were made. In addition any loss of synch and of data as well as recordings of calibration signals were noted. From these logs we have compiled a table giving the exact times for each mode of spectrometer's operation and the total number of scans that are free of any problems and hence can be used in averaging. On the basis of this information we have averaged various portions of the spectrometer data obtained by LASP during flights # 3, 4, 12 and 13 in 1969.

In computing the absolute intensities of auroral emissions it is necessary to have accurate information about the spectrometer resolution employed in making the measurements as well as data relating to the absolute calibration of the spectrometer. Since some uncertainty exists in the information relating to the slit width, of the half meter spectrometer, used in some portions of the 1969 flights and because of the absence of strong line features in the spectra monitored with this instrument during these periods, from which one could compute the resolution, it became necessary to utilize band profiles to assess the slit-widths employed. We have therefore synthesized band spectra, at various resolutions and rotational temperatures, for comparison with measured band profiles. Figure 5 shows a synthetic spectrum of the (0-0) and (1-1) bands of N_2^+ 1NG system at 5A resolution and at a rotational temperatures of 250°K. We compare this synthetic spectrum with the measured spectral profile, shown in figure 6, of these two bands monitored with half meter spectrometer, operating at a frequently used slit setting of 20 ($\Delta\lambda/\lambda \simeq 7.85 \times 10^{-4}$).[25] The spectrum shown in figure 6 represents the sum of nine scans, monitored, around Fort Churchill in nighttime aurora, between UT 0533 and 0541 during flight # 4 in 1969. It is clear, on superimposing the theoretical spectra on the measured band profile, that the slit setting 20 of the half meter Ebert spectrometer corresponds to a resolution of about 5A at wavelengths around 3900A. In addition the effective rotational temperature of N_2 $(X^1\Sigma_g^+)$ appears to be about 250°K which corresponds to a height of about 108 kms.[31] Only electrons with energies greater than 10 keV can penetrate to this height.[32] It is interesting to note that the 6300 intensity during this period was less than 200R while the average intensity of the OI green line was more than 2 kR, giving the red to green ratio, for the auroral components; of less than 0.05 compared to a mean value of about 0.13 in most night time auroras. Hence it is conceivable that these measurements, made towards the end of flight # 4 in 1969, correspond to an aurora more akin to type-B than to normal auroras.

One last point worth noting in connection with the computation of the absolute intensities of auroral emissions, observed with the half meter spectrometer, relates to the absolute calibration curves of this spectrometer and the notation of 10X and 100X assigned to the spectrometer outputs recorded on channels # 6 and 5 respectively of the magnetic tapes. On comparing the intensity of the (0-0) band of N_2^+ 1NG system from 10X and 100X output of the half meter spectrometer with those of the Lockheeds Research Laboratory's and Johns Hopkin University's photometer measurements of the N_2^+ 1NG(0-1) band we find that the former two are high by a factor of 10 and 100 respectively. Clearly the absolute calibrations must have been performed without routing the spectrometer outputs through the 10X and 100X amplifiers.

Data from the Johns Hopkins University's one meter Ebert spectrometer have been similarly reduced. It should be noted that the combined requirements of common aurora covering the full fov of all detectors, which provided the data for the analysis reported here, and the need to concentrate only on those periods of measurements during which the intensities of the auroral emissions were steady, limited the data reduction and analysis to a few spectrometer-scans obtained during relatively bright auroras. For most of these scans the auroral features were bright enough to render averaging unnecessary. Still in reducing the data we averaged a large number of scans and we therefore present a few samples of both single scans from the half and one meter Ebert spectrometers as well as averages of several scans. The absolute intensities derived from single scans are much more reliable since the chances for an aurora to maintain steady rate of emissions during the short period of a single scan (lasting a few tens of seconds) of a spectrometer are much higher than over a long period (running to tens of minutes or even several hours) covered by the scans used in averaging. An exception to this occurred in the mid-day auroras where low levels of signals necessiated long period averaging and the intensities of the emissions maintained their values at an approximately constant level, within a factor of two, over the summation period.

Analysis

The spectra reduced so far have been analyzed to deduce the absolute intensities of various emission features present in these spectra, to compare the spectra, whenever possible, with those reported in the literature and to study any feature or relative intensities of various features which show anamolous behaviors. Rather then discussing all the results together it may be more enlightning to treat each flight separately.

1. Flight # 21 (1968): An intense westward traveling surge? passed in the aircraft's zenith around UT 0715. Figure 7 shows the all-sky camera picture of this event taken around UT 0715, and the spectra obtained at this time from the half and one meter Ebert spectrometers are shown in figures 8a, 9a and 9b. Note that the auroral brightness varied considerable during the single-scan period of both the spectrometers. We therefore present, in figures 8b, 9c and 9d, spectra from the same aurora taken a few minutes later when the intensities of the emissions were relatively constant.

During this event the half meter spectrometer was scanning from 3000 to 4000A with scan period of about 16.5 seconds. Prominent auroral emission features in this region include N_2^+ 1NG and N_2 2PG bands. Some weak emissions from the N_2 VK system as well as some atomic lines also lie in this wavelength range.

The one meter Ebert spectrometer was scanning the wavelength region from 1200 to 1400A, with a scan period of 15 seconds, simultaneously in 2nd, 3rd and 4th order. The red lines of OI, Hα, the N_2 1PG bands and the N_2^+ Meinel bands fall in the 2nd order of this wavelength range while the bands of N_2^+ 1NG, N_2 2PG and N_2 VK bands as well as some atomic lines from oxygen and nitrogen lie in the 3rd and 4th orders. Absolute intensity curves for the 2nd and 3rd and 4th order spectra are presented in figures 9e, 9f and 9g.

Several changes in spectrometer's slit width and gain were made during this period and to avoid mixing spectra obtained at different resolution and/or photomultiplier-tube-gain the spectrometer scans covering the duration of this aurora were summed in four different sets of four, three two and eighteen scans. Figures 10a to 13b present the averaged spectra. The absolute intensity curves for these spectra will be presented later. No unusual emission features or abnormal intensity distribution of the auroral emission occurred during this intense westward traveling surge.

2. Flight # 3 (1969): Figure 14 shows a surge which developed around UT 0544 and continued until about UT 0557. Unfortunately the half meter spectrometer was in the calibration mode during the most intense period of the surge and hence we must use the data obtained towards the end of the surge (at UT 0556) for comparison with the measurements from the one meter spectrometer. The single scan of the auroral spectrum between 3000 and 4000A monitored with the aid of the half meter Ebert is shown in figure 15 while output from the one meter spectrometer, covering the wavelength region from 6300 to 6900A in second order, is shown in figure 16. Figure 17 shows the sum of six scans obtained from the half meter spectrometer, over the period UT 0554 to 0557. The spectrum of the red emissions monitored during the period

of most intense surge activity, for which no corresponding measurements in the ultra violet and blue regions are available, is shown in figure 18. Table 2 lists the intensities of various N_2 1PG bands during the early period of this surge and the intensity of the N_2 1PG system derived from these bands as well as the intensities of the N_2 2PG(0-0) band and the green and red lines of OI. The time history of the N_2 1PG intensity is sketched in figure 19 which illustrates the rapid variations occurring in the emissions from N_2 $B^3\Sigma_g^+$ states. We hope to extend table 2 and figure 19 to cover the entire surge period.

Flights # 12 and 13 (1969):

Mid-day auroras were observed during both these flights, from Bodo to Greenland and back, and data relating to optical emissions in the UV; blue and red regions were gathered using the two spectrometers. Measurements, in the 3000 to 4000A region, made with the half meter spectrometer, show that the auroras encountered in the mid-day section of the oval may be grouped into two sections. The first group is characterized by moderate intensities of auroral optical emissions and relatively brighter VK band emissions. these features are illustrated in figure 20 which shows two spectra, recorded during flight # 13 in 1969 over the period UT 0814 to UT 0818. (A wavelength scale and a chart, marking the position of various auroral emissions features on this scale, are displayed in figure 21. This scale and chart can be superimposed on figures 20, 24 and 25 using the N_2^+ 1NG (0-0) band, appearing on the night end of each spectrum, to line up the wavelength scale.) Note the intensities of the N_2 VK (1-9), (1-10) and (1-11) bands relative to N_2^+ 1NG (0-0) and N_2 2PG (0-0) bands. Compared to their relative intensities in the spectrum of the night-time aurora, shown in figure 15 which covers the same spectral range, it is evident the VK bands are relatively brighter in the mid-day auroras. This could indicate a relatively lower characteristic energy for the precipitating auroral particles and consequently a relatively higher altitude for the peak emission regions, where lower ambient densities would lead to fewer de-existing collisions and higher probability for radiative transitions from A $^3\Sigma_u^+$ to X $^1\Sigma_g^+$ states of N_2. The second group of mid-day auroras are characterized by weak intensities of optical emissions and a vibrational and rotational distribution of the N_2 1NG bands different from that encountered in night-time auroras. In figures 22 and 23 we have reproduced the all-sky camera pictures of such auroras encountered during flight # 12 and 13. Auroral optical spectra, covering the same wavelength region as in figures 15 and 20, taken around UT 0835 during flight # 12 (1969) and between UT 0658 and UT 0710 during flight # 13 (1969) are displayed in figures 24 and 25. It is evident, on comparing figures 24 and 25 with figure 15, that relative to the (0-0) band a N_2^+ 2NG the (1-1) band of this system is more intense in the mid-day auroras. This is shown more clearly in figures 26 and 27 which represent the sum of all scans recorded, with the half meter spectrometer, between UT 0811 and 0851 during flight # 12(1969) and between UT 0650 and 0731 during flight # 13 (1969). We also show in figure 28, a synthetic spectrum of the N_2^+ 1NG (0-0) and (1-1) bands for a rotational temperature of 3500° K and zero vibration temperature — for the electronic ground state of N_2. Comparing figures 26 and 27 with figure 28 it is apparent that both the rotational and vibrational temperature of N_2 electronic ground state are much higher in the regions where mid-day auroral optical emissions originate than at the altitudes where night-time auroral emissions peak.

The one meter spectrometer was scanning between 6800 and 7000A in second order, both during flight # 12 and flight # 13. So far we have found no signs of N_2^+ Meinel bands during the period when the half meter recorded anamolous intensities of N_2^+ 1NG (1-1) band. Figure 20 shows a partial sum of the spectra recorded with the one meter Ebert during flight # 12 (1969). All the prominent features in this spectra can be identified as the vibrational-rotational features of the (7-2) band of OH. It must be stressed here, however, that the reduction of these data is still continuing and that further analysis may alter this picture.

The above reported measurements constitute the first observations ever made of the anamolous intensity distributions of N_2^+ 1NG emissions in the cusp regions. These measurements provide interesting information which may advance our understanding of the atomic and molecular processes in the lower thermosphere.Such observations may also contribute towards an understanding of the problems relating to vibrations temperature of N_2 $X^1\Sigma_g^+$ at various altitudes in the atmosphere, the reactions which preferentially populate higher vibrational levels ofN_2 $X^1\Sigma_g^+$ and perhaps the resonant scattering of solar radiation by N_2^+ ions in $X^2\Sigma_g^+$ and $A^2\Pi_u$ electronic states as well excitation of these states by slow ions. All these processes will be examined,in the section devoted to theoretical considerations,in an attempt to explain the interesting observations relating to the intensities of (0-0) and (1-1) bands of N_2^+ 1NG system.

In addition to the spectrometer measurements, extensive data from the photometer operated by the Lockheed and Johns Hopkins groups are available. Figures 30 and 31 display these photometer measurements for the period UT 0800 to 0900 during flight # 12 (1969). Note the enhancement of 6300 relative to 5577 and the presence of proton precipitation during the period, bounded by dashed vertical lines in these figures, in which anamolous vibrational and rotational distributing of N_2^+ 1NG bands, shown in figure

26, were observed. In addition to the intensities of OI red and green lines, Hβ, N_2^+ 1NG and N_2 2PG bands, the invariant latitude and shadow height during this period are also shown.

It should be stressed at this point that the discovery of an anamolous vibrational and rotational distribution of the N_2^+ 1NG bands culminated from a coordinated analysis of all optical data that have been made available for this project. The Lockheed Research Laboratory's[16] and Johns Hopkins University's[12] photometer data were extensively used in identifying flight periods when the ratios of OI 6300 to N_2^+ 1NG (0-1) band, and the green to red lines of OI, were much higher than normally encountered in night time auroras. In turn such ratios were employed in conjunction with extensive theoretical calculation of Dr. M. H. Rees[25] to determine approximately the characteristic energies of the precipitating auroral electrons and the depth to which they penetrate into the atmosphere.[32] Such analyses suggested the precipitation, in midday auroras, of electron with characteristic energies around 300 eV and which would not penetrate much below 200 kms.[32] On the basis of these results an attempt to search for an increase in the relative intensities of VK bands in mid-day auroras was initiated among the auroral optical spectra furnished by the University of Colorado (LASP) and the Johns Hopkins University. This led to the confirmation of the expected effect as well as to the unexpected information on the anamolous intensity distribution of N_2^+ 1NG bands.

Latitudinal Variation of Nightglow OI(6300A) Emission

Excluding the periods when photo electrons from sunlit conjugate areas contribute to the excitation of OI, the nightglow 6300 emission is produced entirely by dissociative recombination. Hence the intensity of the 6300 emission should be a good measure of the electron density in the F-region.

The latter varies with latitude because of the varying influence of solar radiation with latitude, the ionization caused by precipitating particles in the auroral region and the presence of electric fields, at the equatorward edge of the auroral region, which sweeps out the electron, thereby creating an electron trough.[33] Assuming that during the period of measurements only changes in electron density are responsible for variations in the 6300 intensity we can map the latitudinal variation of the former via zenithal measurements of the 6300 emission aboard an aircraft covering a sizable ($\sim$ 50°) latitude range in a single flight. Figure 32 shows one such measurement, made by Eather and Mende[F] using a tilting filter photometer, during a period when the N_2^+ 1NG emissions were completely absent. Variations in the 6300 emission shown in this diagram closely parallel changes in electron density, made at completely different times by other investigators.[33] While these measurements do not constitute a proof that the variation in the red line intensity around 60° invariant latitude is a reflection of the spatial distribution of the electron trough, the similarity is certainly very suggestive and it would be worthwhile to undertake airborne measurement of 6300 intensity, in conjunction with several groundbased photometers suitably dispersed (at equal latitude intervals) along the flight path to monitor temporal variations for subsequent determination of the true spatial variation of the red line intensity, and hence of the F-layer electron density.

Satellite Coordination

Both during the 1968 and 1969 Airborne Auroral Expeditions several attempts were made to fly under, or in the vicinity of, the trajectories of several satellites or at their conjugate points. Very recently the principal investigators who have their detectors abroad the OGO satellites, with which coordination was attempted, made some particle data available for correlation with optical measurements and this will be attempted later Partial analysis of electron and proton flux from ATS-V and OVI-18 provided by Lockheed Research Laboratores[27] has been attempted. Table 3 gives pertinent details about the attempted coordination while Table 4 lists the electron flux in various energy bands monitored aboard ATS-V during those coordination periods when enhancements in the flux were recorded.

From the known positions of ATS-V and the geomagnetic coordinates of the aircraft, at the time of coordination, we have computed the loss cone at the equator, assuming that particles which do not mirror above 200 kms in the auroral region are precipitated there. This permitted us to use the ATS-V electron-flux data to compute the amount of electron energy precipitated in the auroras during the coordination period. For comparison with the total energy deposition observed in these auroras we have employed Eather and Mende's photometer measurements[16] of the N_2^+ 1NG(0-1) band intensity and a conversion factor: 270 R of N_2^+ 1NG(0-1) band intensity $\equiv$ 1 erg/cm^2 -sec of electron energy deposited in the atmosphere. Table 5 lists the electron energy in the loss cone at ATS-V coordinates and the corresponding values deduced from the optical measurements in the aurora. The ATS-V measurements show that the electron energies in the loss cone around six earth radii above the geomagnetic equator are at least an order of magnitude lower than those released in the auroras. This discrepancy may arise from three sources:

(a) The presence of extremely high flux of low energy electrons (<650eV) in the loss cone that could not be detected by ATS-V particle monitors.

(b) The particle flow-tube from the plasma sheet did not penetrate to the ATS-V's position at the equator, on its way to the auroral latitudes.

(c) Local acceleration mechanism in the magnetosphere above the auroral regions are responsible for energizing the precipitating auroral electrons. At this time no firm conclusion about the true cause of the observed discrepancy can be drawn on the basis of the available data.

Theoretical Considerations

Scientifically, the most interesting results from the analysis of the airborne auroral measurements performed so far relate to anamolous N_2^+ 1NG(0-0)/(1-1) ratio. Several processes that may contribute to this anamoly suggest themselves. These are:

(1) The high ambient temperatures at the heights where the mid-day auroral optical emissions originate lead to relatively higher intensities of the rotational lines with large rotational quantum numbers. In turn this produces a broadening of the (0-0) band of N_2^+ 1NG and a displacement of its R branch hump to lower wavelenghts, overlapping with the bandhead of the (1-1) branch. Hence what appears as an enhancement of the (1-1) band may be merely an intense development of the rotational levels of the (0-0) band. To check out this possibility we have synthesized the (0-0) and (1-1) bands of N_2^+ 1NG using a computer program developed by Dr. V. Degen of the Geophysical Institute at the University of Alaska. This program employs the most recent calculations of Frank Candon factors based on RKR rather than Morse potentials. Unfortunately such improved Frank Condon factors. for the ionization transition $N_2\ X^1\Sigma_g^+ \rightarrow N_2^+\ B^2\Sigma_u^+$ are available only for zero vibrational level of the N_2 (i.e. all $N_2\ X^1\Sigma_g^+$ in v = o). Hence the spectra synthesized from this program give an authentic representation of the effects of high rotational temperature but do not show the contribution from higher vibrational levels of $N_2\ X^1\Sigma_g^+$ on the population of $N_2^+\ {}^2\Sigma_u^+$ vibrational levels.

Earlier we mentioned the ambiguity in the resolution of the spectrometer data furnished by the University of Colorado and the need for synthetic spectra computed at different resolution which can be used to resolve this problem. Hence in synthesizing the (0-0) and (1-1) bands of N_2^+ 1NG system we sought to resolve both the problem related to the spectrometer resolution and the effect of the development of higher rotational levels of the (0-0) band on the overall spread and spectral form of this band. Synthetic spectra at 0.5, 1, 2, 3, 5, 7, 10 and 15 A resolution and for rotational temperatures of 250, 350, 500, 700, 1000, 1500, 2000, 2500, 3000 and 3500° K were computed. We show two samples of these synthetic pectra in figures 5 and 26. Copies of all other calculated spectra are available.

Comparing the spectra of the N_2^+ 1NG (0-0) and (1-1) bands observed in the mid-day auroras (figure 26 and 27) with the synthetic spectra, shown in figure 28, we notice that the measured profile of (0-0) band certainly corresponds to higher rotational temperature than was observed in night-time auroras; the higher rotational levels of the R branch are certainly more intense. Yet the strong feature around the wavelength corresponding to the bandhead of the (1-1) band of N_2^+ 1NG cannot be explained as rotational development of the R branch at high rotational temperatures. More likely it represents the enhanced intensity of the (1-1) band itself since the observed feature certainly coincides with the bandhead of the (1-1) band. Hence one must look at the possibility of high vibrational temperature of N_2 $X^1\Sigma_g^+$.

(2) Studies of the vibrational temperature of N_2 in the E and F regions were first undertaken by Jamshidi.[34] Bauer et al[35] give the following model:

The lower thermosphere is far from LTE (Local Thermodynamic Equilibrium) with effective N_2 population temperature for 80 kms $\leq$ h $\leq$ 300 kms in the range 180°K $\leq$ T $\leq$ 4000° K; and because the vibrational contribution to the heat capacity is in the quantum mechanical (low temperature) rather than the classical (high temperature) regime under these conditions, the vibrational energy content will vary over four to five orders of magnitude at 100 kms depending on the effective vibrational temperature.

To reduce this uncertainty all population-depopulation processes occuring in the atmospheric region of interest must be considered. Center and Caledonia[36] give the following master vibrational rate equation for the density of molecules N in vibrational level v:

$$
\begin{aligned}
dN_v/dt = {} & \sum_i Z_{N\text{-}M_i} \sum_{v_i} \Big\{ P^{v-1,v}_{v_i-v_{i-1}} \left[N_{v-1} N_{v_i} - N_v N_{v_i-1}\, e^{(\Delta E_v - \Delta E_{v_i})/kT} \right] \\
& + P^{v+1,v}_{v_i,v_i+1} \left[N_{v+1} N_{v_i} - N_v N_{v_i+1}\, e^{(\Delta E_{v_i+1} - \Delta E_{v+1})/kT} \right] \Big\} \\
& + \sum_i Z_{N\text{-}M_i} \Big\{ P^{v-1,v}_{i_v\text{-}T} \left[N_{v-1} - N_v\, e^{(\Delta E_v/kT)} \right] + P^{v+1,v}_{i_v\text{-}T} \left[N_{v+1} - N_v\, e^{-(\Delta E_v/kT)} \right] \Big\} M_i \\
& + N_{v+1}/\tau_{v+1} - N_v/\tau_v .
\end{aligned}
$$

Here single quantum transition is assumed. $Z_{N\text{-}Mi}$ is gas kinetic collision frequency of species N colliding with species M_i at unit concentrations. The first bracketed expression refers to vibration-vibration (v-v) collisions, exchange processes, where $P^{v,v-1}_{vi,vi+1}$ is collisional probability. The exponential term arises from detailed balancing assuming a Maxwellian velocity distribution corresponding to translational temperature T. The second bracketed expression refers to the vibration to translation (V-T) collisional process. The last two terms denote radiative decay, where τ_v is the radiative lifetime of level v.

The physical processes which affect the vibrational population of a molecular species M can be more clearly seen, and appreciated, by considering an idealized situation where only the v=0 and v=1 levels are involved in the following population-depopulation processes:

$$M(v=0) + X \underset{k_2}{\overset{k_1}{\rightleftharpoons}} M(v=1) + X \qquad (1)$$

$$P \quad + \quad Q \quad \underset{k_4}{\overset{k_3}{\rightleftharpoons}} M(v+1) + R \qquad (2)$$

$$M(v=0) + h\nu \underset{q_2}{\overset{q_1}{\rightleftharpoons}} M(v=1) \qquad (3)$$

where P, Q, X and R are various other chemical species and the effective rate constants k and q have dimensions of cm^3/sec and sec^{-1} respectively.

Hence $\dfrac{\partial n(1)}{\partial t} = n(0)(k_1 n_{tot} + q_1) + k_3 n_P n_Q - n(1)(k_2 n_{tot} + k_4 n_N + q_2)$ (4)

where n refers to number density of various species.

In a steady state situation $\dfrac{\delta n(1)}{\delta t} = 0$ (5)

so that $\exp(-hc\,\omega_e / kT_{vib}) = n(1)/n(0)$

$$= \frac{k_1 n_{tot} + q_1 + k_3 n_P n_Q / n(0)}{k_2 n_{tot} + k_4 n_N + q_2} \qquad (6)$$

where ω_e = vibration frequency (cm^{-1}). For the general case of a harmonic oscillator rather than the two-state model

$$T_{vib} = hc\omega_e k \log_e \left(\frac{k_2 n_{tot} + k_4 n_N + q_2}{k_1 n_{tot} + q_1 + k_3 n_P n_Q / n_{tot}} + 1 \right) \qquad (7)$$

(Homonuclear molecules, like N_2, are infrared inactive, hence both q_1 and q_2 are exceedingly small.)

The main process for producing $N_2(v)$ are

$O(^1D) + N_2 \rightarrow N_2\ (v) + O(^3P)$ (8)

$N + NO \rightarrow N_2\ (v) + O$ (9)

$e^- + N_2 \rightarrow N_2^- \rightarrow N_2(v = 1) + e^-$ (10).

(8) contributes negligible amount to the vibrational excitation of N_2 while (9) may yield one third of the exothermicity in the vibrational excitation. In auroras characterized by precipitation of low energy electron (10) may be important since at the high altitudes where such electrons are stopped the effect of the main collisional de-excitation processes

$$N_2(v) + O \rightarrow N_2O^* \rightarrow N_2 + O \qquad (11)$$

and $N_2(v = 1) + CO_2 \rightarrow CO_2(v = 1) + N_2$ (12)

may be relatively less effective than at the heights ($\sim$ 110 to 130 kms) where the normal night time auroras are formed. At high altitudes diffusion is a significant mechanism for loss of vibrationally excited as well as other species. Hence

$$\langle k_2 n_{tot} + k_4 n_N \rangle \sim D/H^2$$

where molecular diffusivity $D \sim \frac{1}{2} l \bar{c}$, ($l$ = gas kientic mean free path $\sim \frac{1}{\rho}$, $\bar{c}$ = mean thermal speed) of the excited state and $H = kT/Mg$ is the atmospheric scale height, so that D/H^2 is an effective first order rate constant for diffusion.

Breig et al.[37] have shown the special importance of the quenching of vibrationally excited nitrogen molecule (N_2^*) by atomic oxygen (see equation (12) above) in a direct vibration-to-transulation energy transfer process in the lower thermosphere. They have calculated the N_2 vibrational temperature in the lower thermosphere and their results indicate that this temperature may vary between 710°K and 3350°K in the 200 to 300 kms atmospheric altitude range. Earlier calculations by Walker et al.[38] yielded the values of 1200°K to 3650°K for the same altitude range.

On the basis of the above discussion we have attempted to compute the ratio of the (0-0) to (1-1) bands of N_2^+ 1NG systems for various vibrational temperatures of N_2 $X^1\Sigma_g^+$ states. These calculations require, among other things, information about the Frank Condon factor for

$$N_2^+ (X^1\Sigma_g^+, v = 0,1,2,\ldots\infty) \rightarrow N_2^+ (B^2\Sigma_u^+ v'' = 0 \text{ and } 1) \quad (13)$$

as well as for $N_2^+ (B^2\Sigma_u^+ v = 0 \text{ and } 1) \rightarrow N_2^+ (X^2\Sigma_g^+, v'' = 0 \text{ and } 1)$ (14)

We pointed out earlier that the more exact Frank Condon factors are only available for ionization transitions from the zeroth vibrational level of the electronic ground state ($X^1\Sigma_g^+$) of N_2. Consequently we must employ the corresponding, more extensive values computed by Nicholls[39] using Morse potentials.

Figure 33 shows the ratio of the (0-0) to (1-1) bands of N_2^+ 1NG as a function of vibrational temperature of $N_2(X^1\Sigma_g^+)$. Contributions to the v=0 and 1 levels of N_2^+ ($B^2\Sigma_u^+$) from v=0 to v=15 level of N_2 ($X^1\Sigma_g^+$) have been included. Note that upto 600°K the contribution from the vibrational levels of N_2 ($X^1\Sigma_g^+$) other than the zeroth level to the population of the vibrational levels of N_2^+ ($B^2\Sigma_u^+$) is negligible. However, at the ambient temperatures prevailing in the 200 to 300 km region of the earth's atmosphere, these calculations show that the ratio of the two bands is markedly different from the values appropriate for the 110 to 130 kms regions where most of the night time auroral emissions peak.

From Figure 26 the average ratio of the (0-0) to (1-1) bands of N_2^+ 1NG, over the time interval from UT 0811 to 0851, was 8. This suggests a vibrational temperature of 2650° for $N_2(X^1\Sigma_g^+)$ at the height where optical emissions in the mid-day auroras, peak. It should be stressed here that the intensities of the (0-0) and (1-1) band of N_2^+1NG were obtained by measuring the area under the curves of these bands. such a method of obtaining relative band intensities is quite crude, especially for partly overlapping bands and because of the difficulty in assesing the contributions from high rotational levels. One may appreciate the magnitude of this problem by analyzing similar measurements from the night-time auroras. From figures 5 and 6 we get a ratio of 39 for the two bands, while the theoretical value at the temperature which corresponds to the measured profile of the (0-0) band (i.e. 250°K) is 23.6. Apparently in computing the area under the (1-1) band the contribution from its short wavelength tail is not adequately evaluated. If we use the factor of 23.6/39 to scale down all other values of the measured ratios of these two bands we would get a value of 5 in the mid-day auroras. While the ratio of 8 corresponds to a vibrational temperature of 2650°K, the ratio of 5 implies even a higher vibrational temperature, approximately 5000°K. The measured profile of the (0-0) band in the mid-day auroras appears to approximate a rotational distribution corresponding to a temperature exceeding 3500°K.

According to Breig et al[36] the maximum N_2 vibrational temperature, in the absence of OI quenching, should be 3200°K at 200kms and 3350°K at 300kms. Quenching by OI has the effect of lowering these values to 1800°K and 2200°K respectively. It is premature at this stage to attempt any comparison between various theoretical calculations of N_2 $(X\ {}^1\Sigma_g^+)$ vibrational temperature in the F region and our measurements of the N_2^+ 1NG bands in the mid-day auroras. We must first extend the computer program, for synthesizing band profiles of N_2^+ 1NG system, to include the effect of high temperatures on the vibrational population of N_2 electronic ground states. We must also await results from refined calculations of Dr. M. H. Rees (on the ratio of the OI 6300 emission to N_2^+ 1NG (0-1) band as a function of characteristic energy of precipitating electrons) which will permit us to infer the height at which optical emissions from mid-day auroras peak. Together, the results of all these theoretical studies when compared with auroral measurements in the mid-day auroras may yield scientifically useful results on the non-equilibrium processes that occur in the upper atmosphere (and may permit an assessment of the possibilities of using the lower thermosphere as a potential laboratory for the observations of non-equilibrium processes.)

(3) Resonant Scattering of Solar Radiation by N_2^+ Ions: Another mechanism which could alter the ratio of the (0-0) to (1-1) bands of N_2^+ 1NG in the mid-day auroras, from its value in night-time auroras, is the resonant scattering of solar radiation by N_2^+ ions at the low shadow height (270 to 370 kms) during the midday aurora. For the solar depression angles corresponding to the shadow heights in mid-day auroras the ionizing component of the solar radiation (XUV) is filtered out by the intervening mass of air between the F region, at the mid-day auroras' location, and the path along the direction of the solar radiation. Hence the solar radiation does not contribute to the production of N_2^+ ions which must be formed mostly by the precipitating electrons. (The effects of solar radiation and photo electrons in the excitation of N_2^+ ($B^2\Sigma_u^+$) vibrational levels are important in the dayglow. This problem has been treated by several authors notably Broadfoot[42] and Feldman).[43]

Bates (1949)[40,41] showed that resonsance scattering of solar radiation by N_2^+ 1NG ions lead to an intensity distribution of the N_2^+ bands similar to one which would result from equilibrium with the solar radiation i.e. a distribution corresponding approximately to a vivrational temperature of 4200°K. On the otherhand the intensity distribution of the N_2^+ 1NG bands in sunlit aurora observed by Vallance Jones and Hunter (1960)[44] appeared to be close to that which would result from fluorescent excitation of ions in the distribution for themal equilibrium at approximately 2050°K. Analyses, of the mid-day auroral data, performed so far suggest a vibrational temperature value lying in between the above two values. In addition the rotational temperature of N_2^+ 1NG (0-0) band appears to be higher than the vibrational temperature and certainly higher than the value of 2100°K observed by Vallance Jones and Hunten [44] for the rotational temperature of N_2^+ 1NG (0-1) band.

Theoretical studies of the resonance scattering of solar radiation by N_2^+ ions are extremely involved (see Vallance Jones and Hunten[44] (1960), also Hunter [45] (1963)) and we must await results of further analysis as well as Dr. Rees' computation, relating to the ratio of OI6300/N_2^+ 1NG(0-1) as a function of characteristic energy of precipitating electrons, before undertaking this task. The latter may assist in determining the significance of resonant scattering of solar radiation during mid-day auroras when shadow heights exceeded 270 kms.

Excitation of N_2^+ 1NG bands by precipitating ions

The rotational distribution of N_2^+ 1NG bands may be altered significantly by reactions involving ions. Extended rotational development of N_2^+ 1NG (0-0) band observed by Broadfoot and Hunten (1966)[46] led Dalgarno and McElroy(1966)[47] to invoke the following reaction:

$$N_2^+(X\ ^1\Sigma_g^+) + O^+(^2D) \rightarrow N_2^+(A^2\pi_u,\ v'=1) + O.$$

The signifcance of this reaction in night-time auroras is questionable in light of Zipf's(1969)[48] measurement of the reaction rate and Gattinger and Vallance Jones"(1973)[49] observations of N_2^+ Meinel bands in auroras. Yet at the heights where mid-day auroras are formed, the larger density of O^+ may raise the contribution on N_2^+ ions from this reaction.

A more significant factor in altering the normal vibrational and rotational distribution of N_2^+ 1NG bands may be the inelastic collisions of ions with N_2. Moore and Doering (1968)[50] observed such an effect in the laboratory and its significance in auroral emissions was confirmed through the measurements of Degen et al(1972)[51] in proton auroras. Since weak proton precipitation was detected by Eather and Mende[16] during the period when an enhancement in the relative intensity of N_2^+ 1NG (1-1) band was ovserved in mid-day auroras, it is possible that inelastic collisions between these protons and N_2 led to an anamolous vibrational and rotational distribution of N_2^+ 1NG bands. Objections to this explanation could be based on the absence of any such effects in most night-time auroras when H_β intensity at least an order of magnitude higher than that observed in mid-day auroras, were recorded. This can be countered by the fact that in night-time auroras most of the N_2^+ 1NG emissions arise from electron excitation and peak around 120kms, while protons may be stopped at relatively higher altitudes. On the otherhan, in mid-day auroras the weak auroral emissions originate in the F regions where proton impact may contribute a significant portion of the observed N_2^+ 1NG emissions. Alternatively one could invoke precipitation of heavy ions of the type reported by Shelley et al(1972)[52]. The fact that such precipitations were observed mostly during magnetically disturbed periods and only at L values between 2.4 and 9 may exclude this source in mid-day auroras which were observed during magnetically quiet periods ($k_p = 1^-$) and at L values between 18 and 39.

Summary and Conclusion

A lot of preliminary work and analyses that we proposed to undertake during the first year under NASA grant NGR 02-001-099, have been accomplished. In the process scientifically interesting data from midday auroras have been found. Further detailed analysis of the spectra presented in this report as well as from other flights must be carried out. Detailed analysis of the mid-day auroral spectra and theoretical understanding of the observed phenomena must be pursued. There is certainly a wealth of data from the 1968 and 1969 Airborne Auroral Expeditions and the analysis of these data is scientifically worthwhile and fruitful, as has been clearly demonstrated from the preliminary work done so far. [redacted]

Even at this early stage of analysis it is evident that further airborne flights for coordinated measurements in the mid-day auroras are scientifically worthwhile. In addition airborne measurements of optical emissions, from proton auroras, frequently sighted over Alaska, during the periods when satellite measurements of EUV auroral emissions as well as auroral electrons and protons are in progress, should provide important information about excitation of atmospheric species by protons, in particular on the questions relating to the relative efficiency of exciting singlet and triplet states by protons and the vibrational distribution of molecules excited by slow protons.

Finally, theoretical work, utilizing satellite data on auroral particle, to explain the observed auroral optical emissions should be started. [redacted]

LIST OF TABLES

TABLE I.

Summary of auroral events which covered the field of view of zenith spectrophotometers

Flight #	U.T.	Type of Aurora	Remarks
			1968
3	0225	Arc	Short-lived, weak aurora.
	0255	Arc	Short-lived, weak aurora.
	0405	Homogenous glow	Stays in fov for about 30 minutes.
	0445	Arc	Short-lived, weak aurora.
5	0235	PcA	Short-lived, weak aurora.
7	0309	Fans and arcs	Weak auroras lasting about 30 minutes.
8	0414-0602	Fans and arcs	Moderately intense auroras.
9	0439-0722	Arcs	Moderately intense auroras.
10	0730	PcA	Short-lived, very faint auroras.
11	0847	Arcs	Short-lived, weak auroras.
16	0900-1200	PcA	Several short-lived, very faint auroras.
17	0337-0410	Arcs and homogenous glows	Several short-lived, very faint auroras.
18	0155-0255	PcA	Several short-lived, very faint auroras.
19	0409-0630	Arcs	Several active auroras.
20	0400-0800	Rayed fans	Strong and active auroras throughout the flight.
21	0504-0926	Breakups	Strong and active auroras throughout the flight.
22	0600-1025	Rayed fans and diffuse glow	Strong and active auroras throughout the flight.
23	0607-0920	Rayed arcs	Strong and active auroras throughout the flight.
24	0610-0952	Faint arcs, PcA	Several short-lived, weak auroras.
25	0603-0952	Arcs, bands and and patches	Several moderately intense auroras.
			1969
3	0218-0240	Arcs	Several, moderately intense auroras.
	0312-0314	Arcs	Several, moderately intense auroras.
	0530-0600	Fans	Intense aurora.
4	0345-0350	Patches	Faint auroras.
	0447-0450	Several arcs	Intense aurora.
	0453-0459	Several arcs	Weak aurora.
5	0611-0707	Arcs and folds	Intense surge.
6	0723	Arcs	Short-lived faint aurora.
7	0540-0545	Arcs	Several weak auroras
8	0630-0750	Arcs	Very weak, short-lived auroras.
	0805	Arc	Very weak, short-lived aurora.
	0905	Glow	Very weak, short lived aurora.
	0945-1105	Arcs and patches	Very weak, short-lived auroras.
9	0557	Arcs	Very weak, short-lived aurora.
	0700-0709	Glow	Very weak, short-lived auroras.
	0815	Glow	Very weak, short-lived aurora.
	0855	Glow	Very weak, short-lived aurora.
	0920	Glow	Very weak, short-lived aurora.
	0940	Glow	Very weak, short-lived aurora.
11	2135-2210	Folds and arcs	Several intense auroras.
12	0800-0930	Patches	Very faint, mid-day auroras.
13	0720-0840	Patches and arcs	Very faint, mid-day auroras.
14	0723	Rayed fans	Intense aurora.

TABLE 2.

Optical emissions from type-B aurora of November 26th 1969. Line and band intensities are given in Rayleighs while the different intensity values of the total N_2 first positive group (1 PG) are quoted in Kilo-Rayleighs.

Universal Time	$N_2$1PG (8-5)	(7-4)	(6-3)	(5-2)	(4-1)	(3-0)	corrected (3-0)	Total corrected Total $N_2$1 PG	OI 6300	5577	N_2^+ING (0-1)	$N_2$2PG (0-0)	(5-2) 1PGN_2 / (0-0) 2PGN_2
0544:51	1312							143.4				475	
52		1580						108.5			825		9.0
53			4824					193.0		5100			
54				7664				255.3	920				
56					3860			152.1				548	8.3
58						1152	1920	k63.5			825		
05:45:06	1660							181.6		4800			
08		1580						108.5	700				
09			2036					81.7				548	4.5
10				2360				78.4			825		
12					2360			92.5					
05:45:13						1044	1740	148.1	540				
22	1476							160.8				573	8.4
24		1928						132.4			825		
25			2036					81.7		6400			
26				1956				65.0	540				
28	2304				2144			84.4				1096	2.3
30						966	1624	133.3			825		
38								251.3		14300			
40		4020						276.0	2350				
41			7772					310.9				1645	5.7
42				7664				255.3			840		
44					6860			270.0		11000			
46						1476	2456	209.7	1650				

	(8-5)	(7-4)	(6-3)	(5-2)	(4-1)	(3-0)	(3-0)
Average Intensity	1688	2280	4180	4904	3804	1152	1936
Ratio to (5-2)	0.34	0.46	-.48	1.00	0.78	0.23	0.39
Theoretical ratio values	0.31	0.49	0.83	1.00	0.85	0.39	

TABLE 3.

Coordination of NASA 711 (CV990) aircraft with ATS-5 and OV1-18 satellites during the 1969 Airborne Auroral Expedition

Flight #	Date 1969	U. T.	Satellite	L	Kp
2	Nov. 24	1215	ATS-5	6.62	2+
3	Nov. 26	0105	ATS-5	6.33	3
4	Nov. 27	0046	ATS-5	6.52	1+
		0521	ATS-5	6.55	4+
5	Nov. 29	0609	ATS-5	6.5	3+
		0632	ATS-5	6.5	3+
8	Dec. 5	1051	ATS-5	6.52	3+
9	Dec. 7	0832	ATS-5	6.52	1+
		0856	ATS-5	6.45	2-
10	Dec. 8	1018	OV1-18	8.08	0+

TABLE 4.

Electron flux from ATS-5 detectors, during the coordination periods in 1961.

Flight #	Electron flux in the energy range 0.65-1.9keV	1.8-5.4keV	5.9-17.8keV	17.4-53keV
2	1.1×10^7	5×10^6	5×10^6	10^6
3	-	-	-	-
4	2×10^8	6×10^7	2×10^7	3×10^6
5	5×10^7	2×10^7	1.5×10^7	3.5×10^6
8	10^8	4×10^7	10^7	1.5×10^6
9	-	-	-	-

TABLE 5.

Energy of electrons in the loss cone and in auroras.

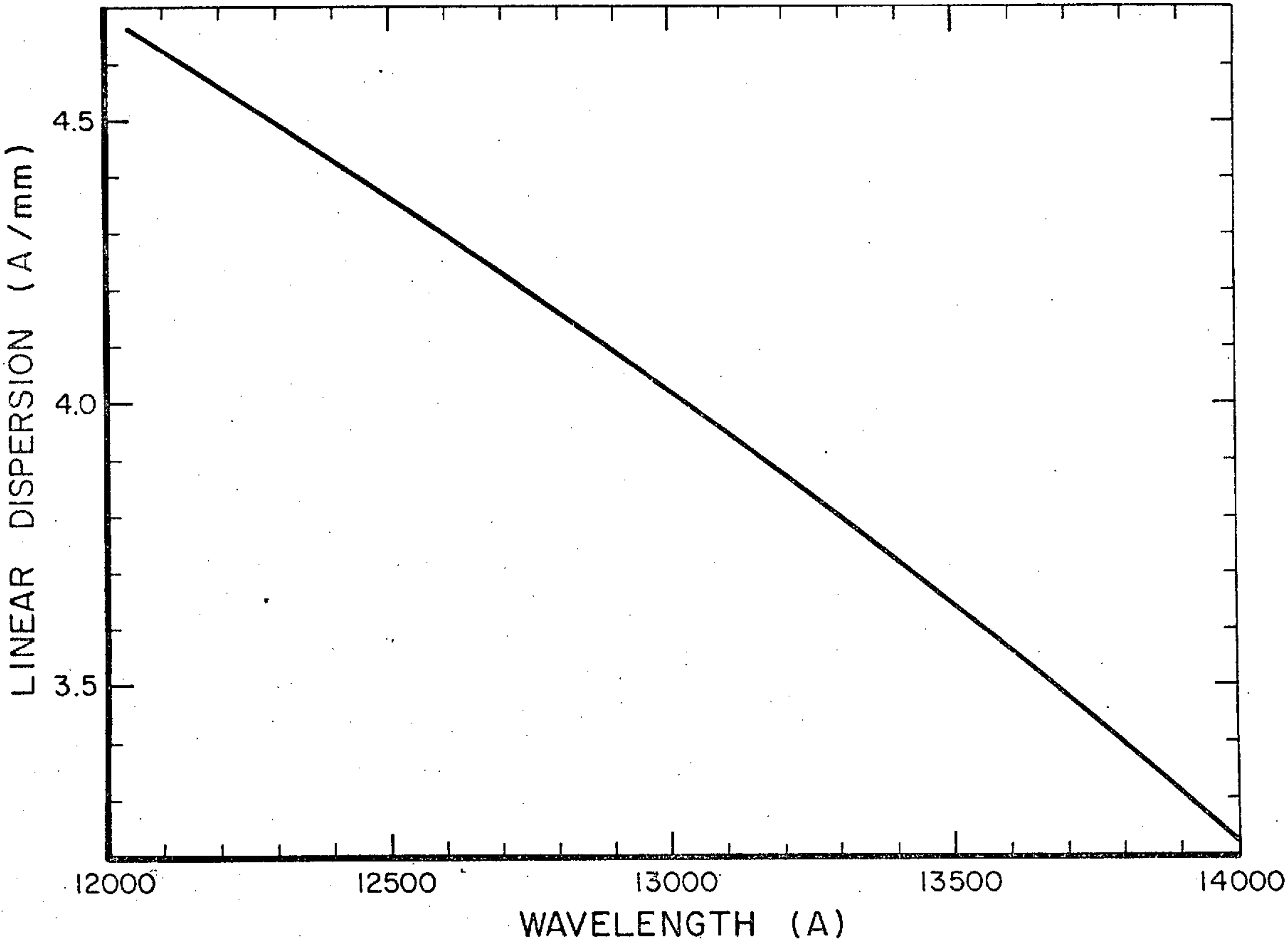
Flight #	N_2^+1NG(0-1) (R)	Electron energy flux in auroras (ergs/cm^2/sec)	Energy flux of electrons in loss cone (ergs/cm^2/sec)
2	23	0.08	0.03
3	30	0.11	0-
4	∿1600	∿5.7	0.12
5	∿500	∿2	0.11
8	∿400	∿1.5	0.13
9	∿800	∿3.0	0-

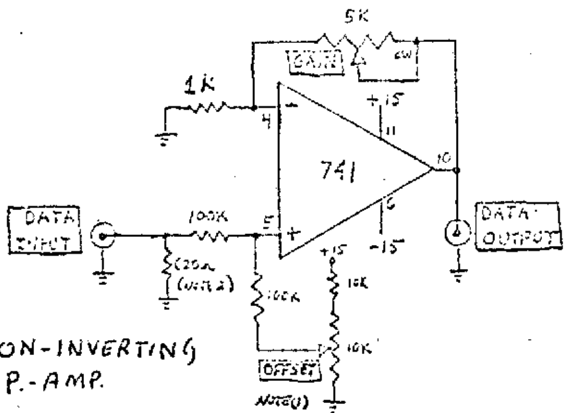
LIST OF ILLUSTRATIONS

Figure #	Contents
9	Single scan of the one meter spectrometer recorded during flight #21 (1968) at a) UT 0713:50 (1X channel) b) UT 0713:50 (10X channel) c) UT 0715 45 (1X channel) d) UT 0715 45 (10X channel).
10	Sum of 4 scans of one meter spectrometer recorded between UT 0712:56 and 0713:56 during flight #21 (1968). Slit width = 1mm Gain = 10. a) 1X channel b) 10X channel.
11	Sum of 3 scans of one meter spectrometer recorded between UT 0713:56 and 0714:41 during flight #21 (1968). Slit width=1mm. Gain = 9 . a) 1X channel b) 10X channel.
12	Sum of 2 scans of one meter spectrometer recorded between UT 0714:41 and 0715:51 during flight #21 (1968). Slit width=1mm. Gain = 8 . a) 1X channel b) 10X channel.
13	Sum of 18 scans of one meter spectrometer recorded between UT 071 and 071 during flight #21 (1968). Slit width = 0.6mm. Gain = 8,9, 10. a) 1X channel b) 10X channel.

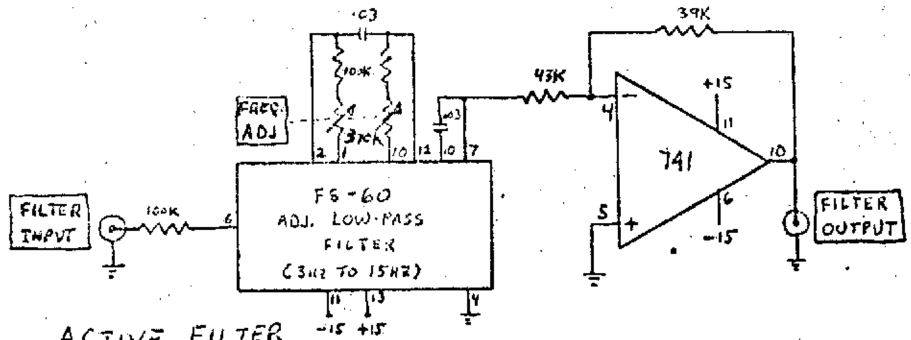
Figure #	Contents
14	All sky camera picture of the aurora recorded around UT 0544 during flight #3 (1969).
15	Single scan of the half meter spectrometer recorded at UT 0556 during flight #3 (1969).
16	Single scan of the one meter spectrometer recorded at UT 0556 during flight #3 (1969).
17	Sum of six scans of the half meter spectrometer recorded between UT 0554 and 0557 during flight #3 (1969).
18	Single scan of the one meter spectrometer recorded at UT 0544 during flight #3 (1969).
19	Time history of the total band intensity of the $N_2$2P system in a surge observed towards the end of flight #3 (1969).
20	Two spectra of the mid-day aurora, each covering the wavelength range from 3000 to 4000 A, observed during flight #13(1969).
21	Wavelength scale and chart of auroral emission features.
22	All sky camera picture of the mid-day aurora recorded at UT 0845 during flight #12 (1969).
23	All sky camera picture of the aurora recorded around UT 0554 during flight #13 (1969).

Figure #	Contents
33	Ratio of the (0-0) to (1-1) bands of N_2^+ 1NG bands as a function of vibrational temperature of N_2 ($X\ {}^1\Sigma_g^+$).

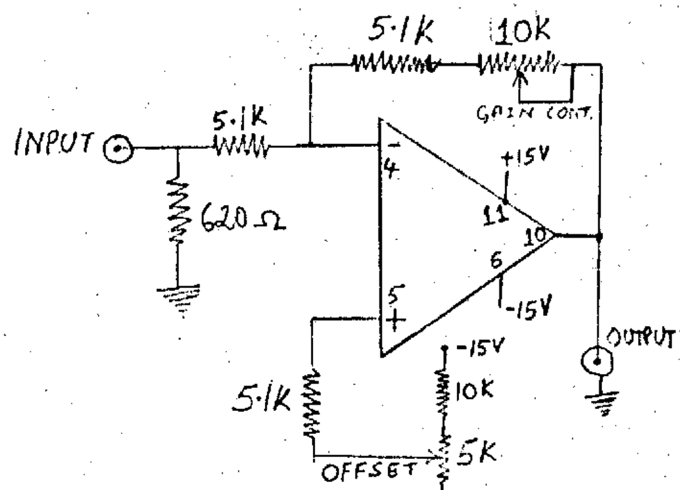

LINEAR DISPERSION (A/mm)
4.5
4.0
3.5
12000
12500
13000
13500
14000
WAVELENGTH (A)



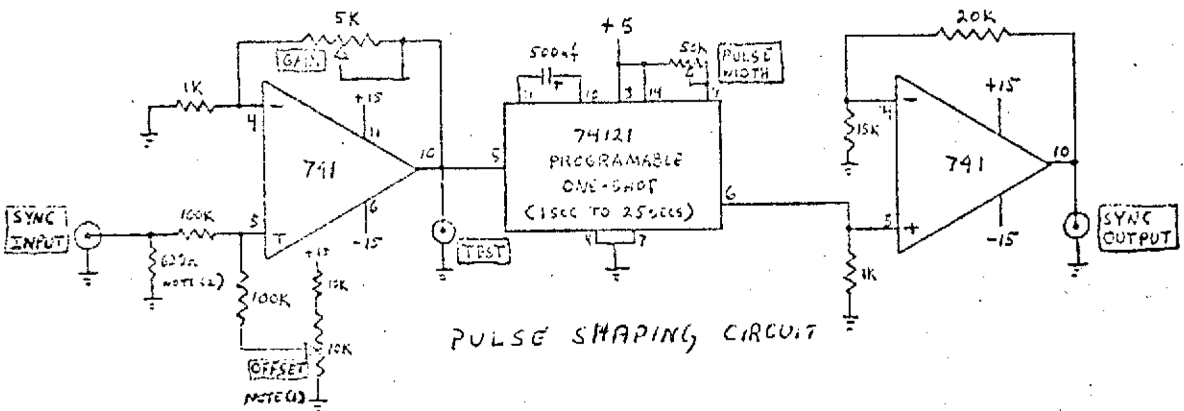
NON-INVERTING OP.-AMP.



ACTIVE FILTER



INVERTING OP.-AMP.

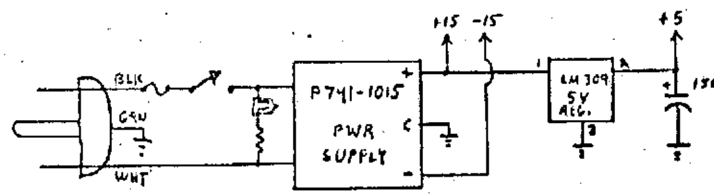


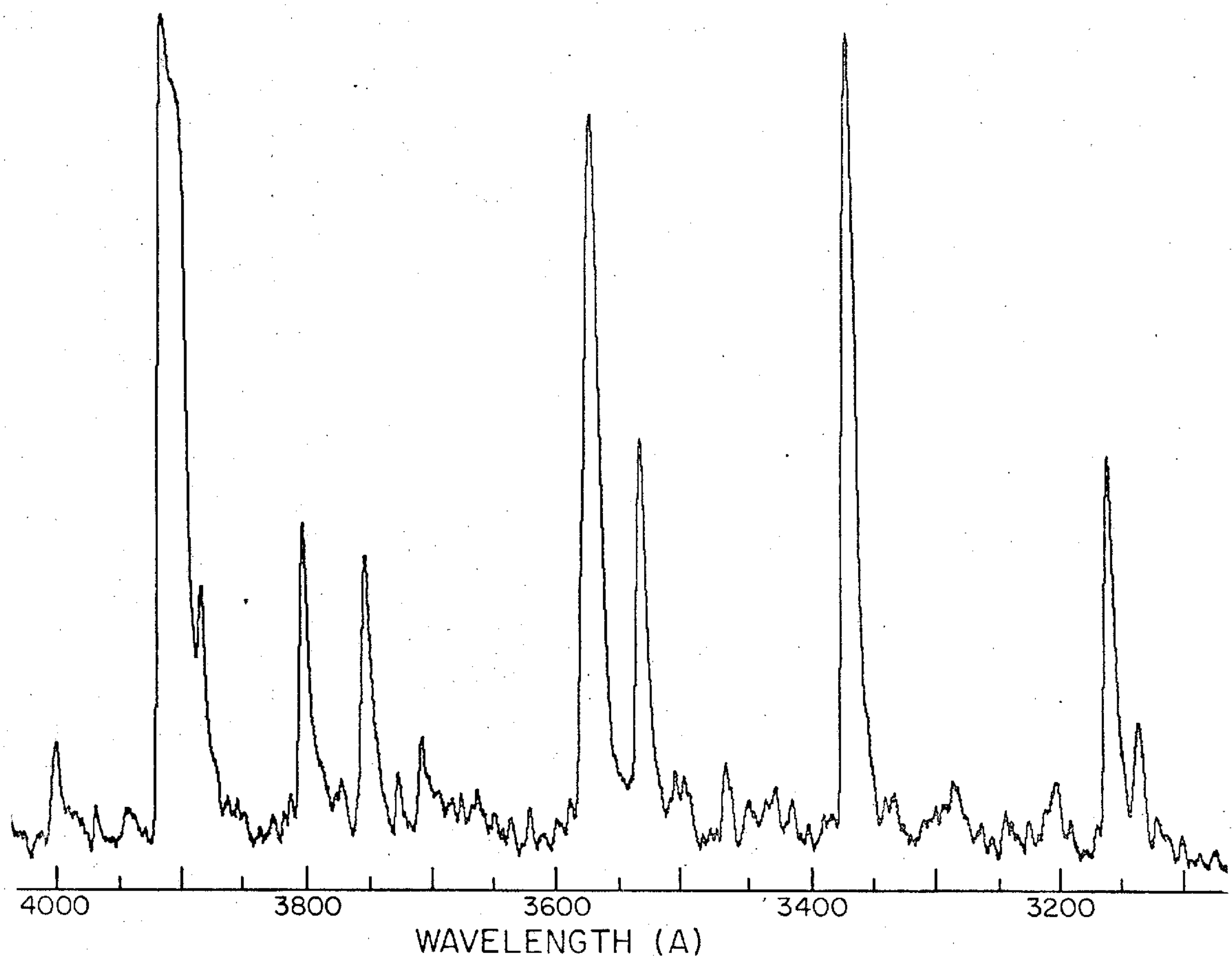
PULSE SHAPING CIRCUIT

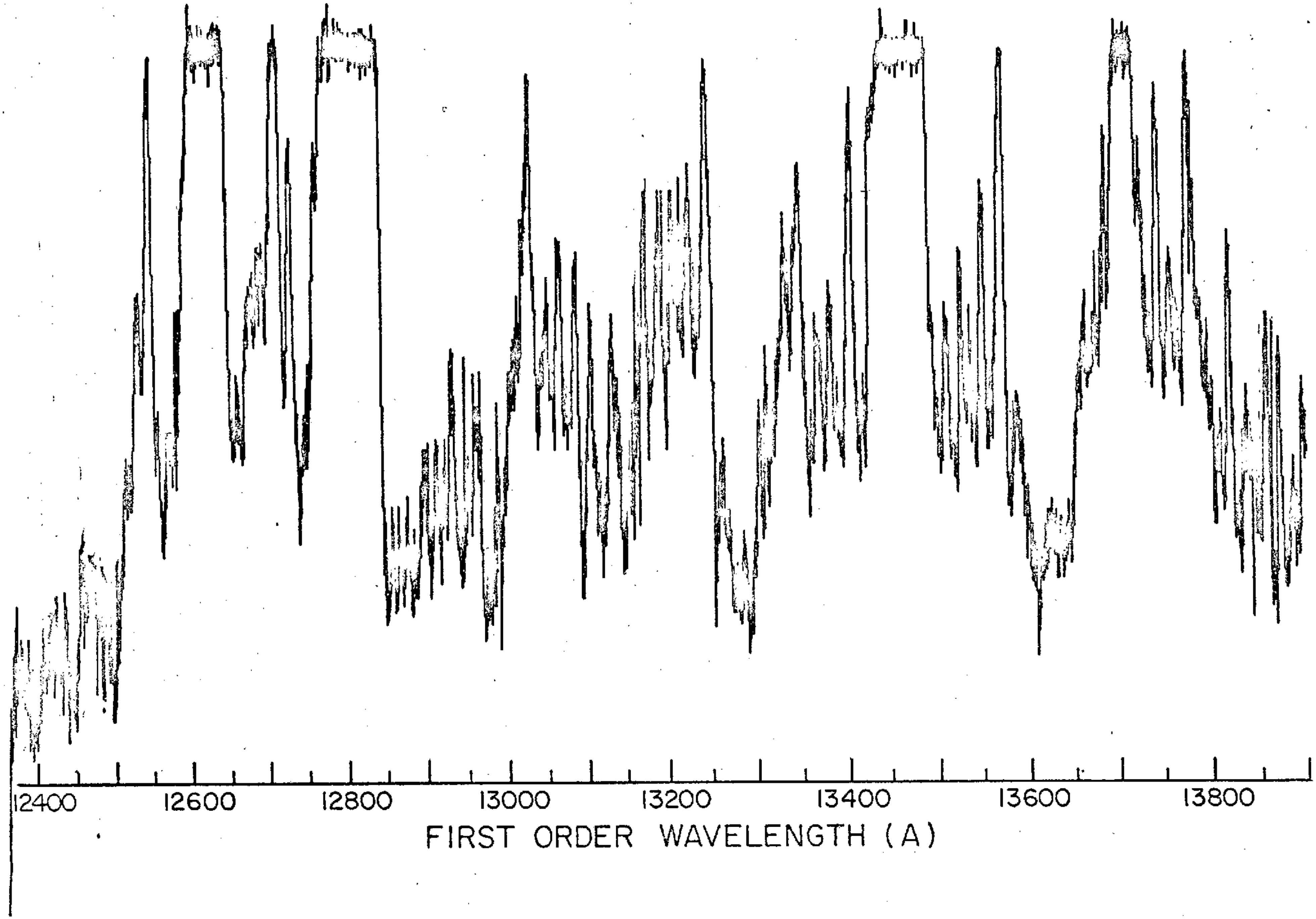
NOTE:

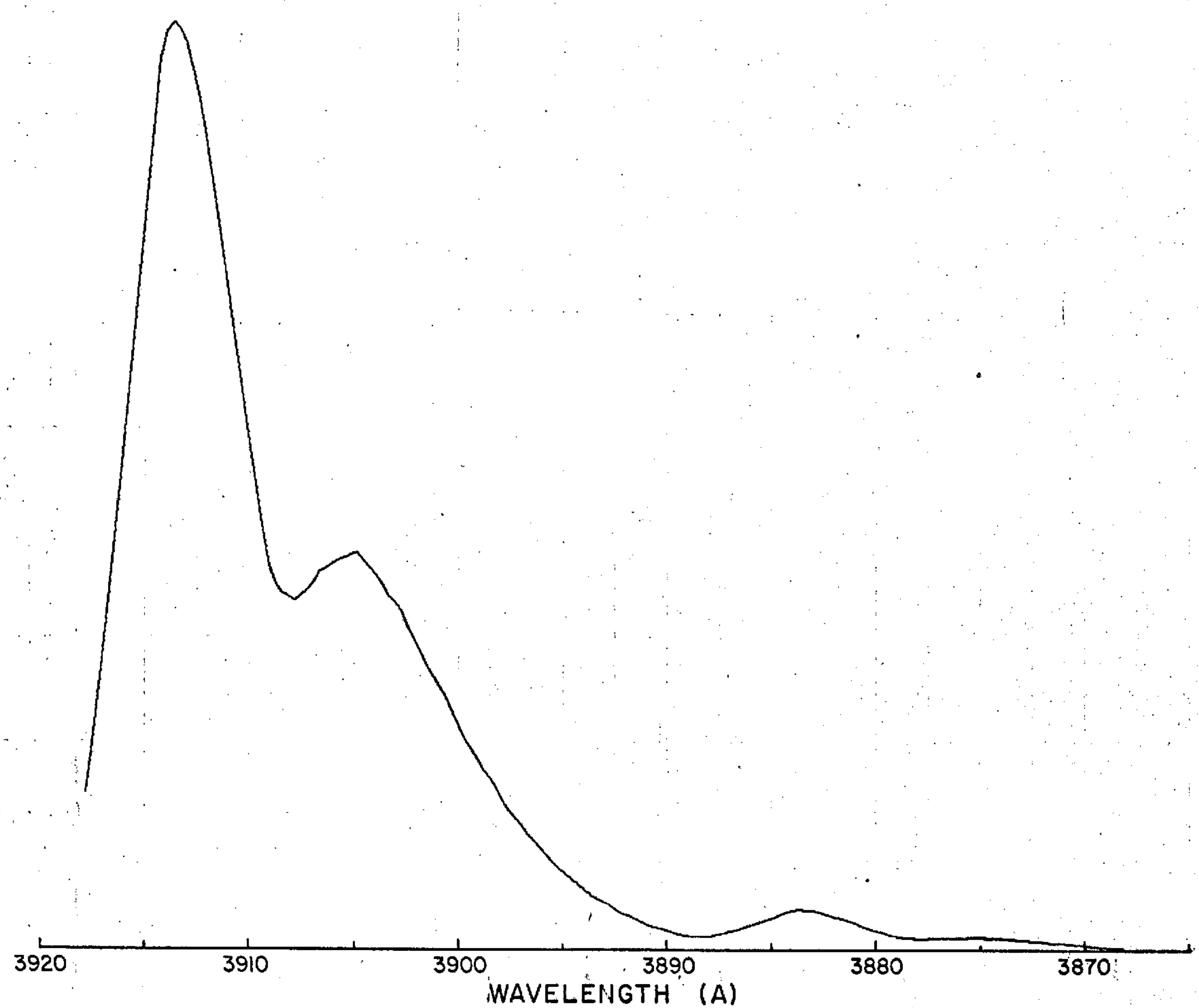
(1) "OFFSET" IS FOR ADJUSTING OUT A NEGATIVE INPUT VOLTAGE. IT CAN BE MADE TO ADJUST OUT A POSITIVE INPUT VOLTAGE BY APPLYING -15 VOLTS TO THE 10K RESISTOR IN PLACE OF THE +15.

(2) THIS 620Ω RESISTOR IS TO PROVIDE PROPER TERMINATION FOR THE P.I. 400 TAPE RECORDER.

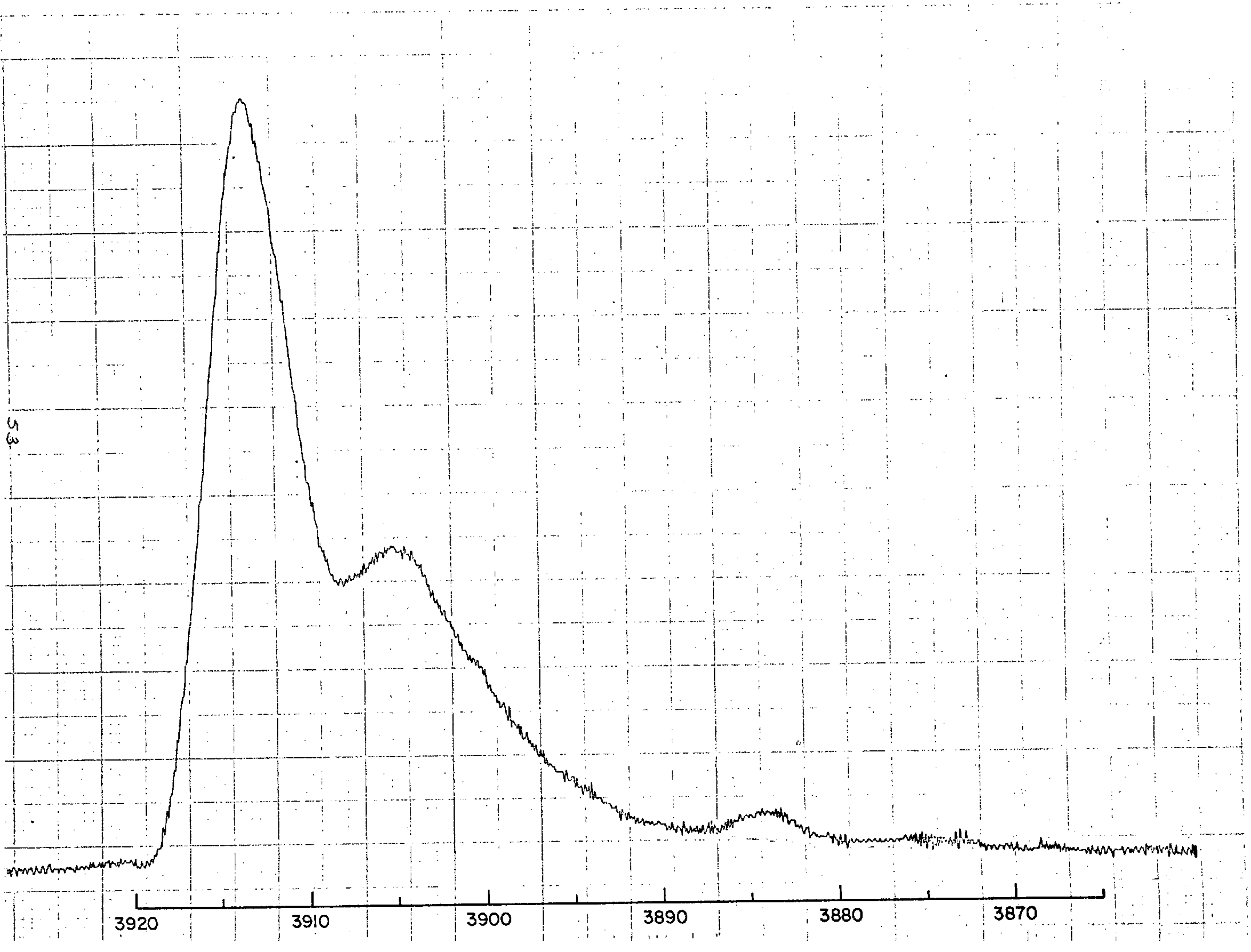


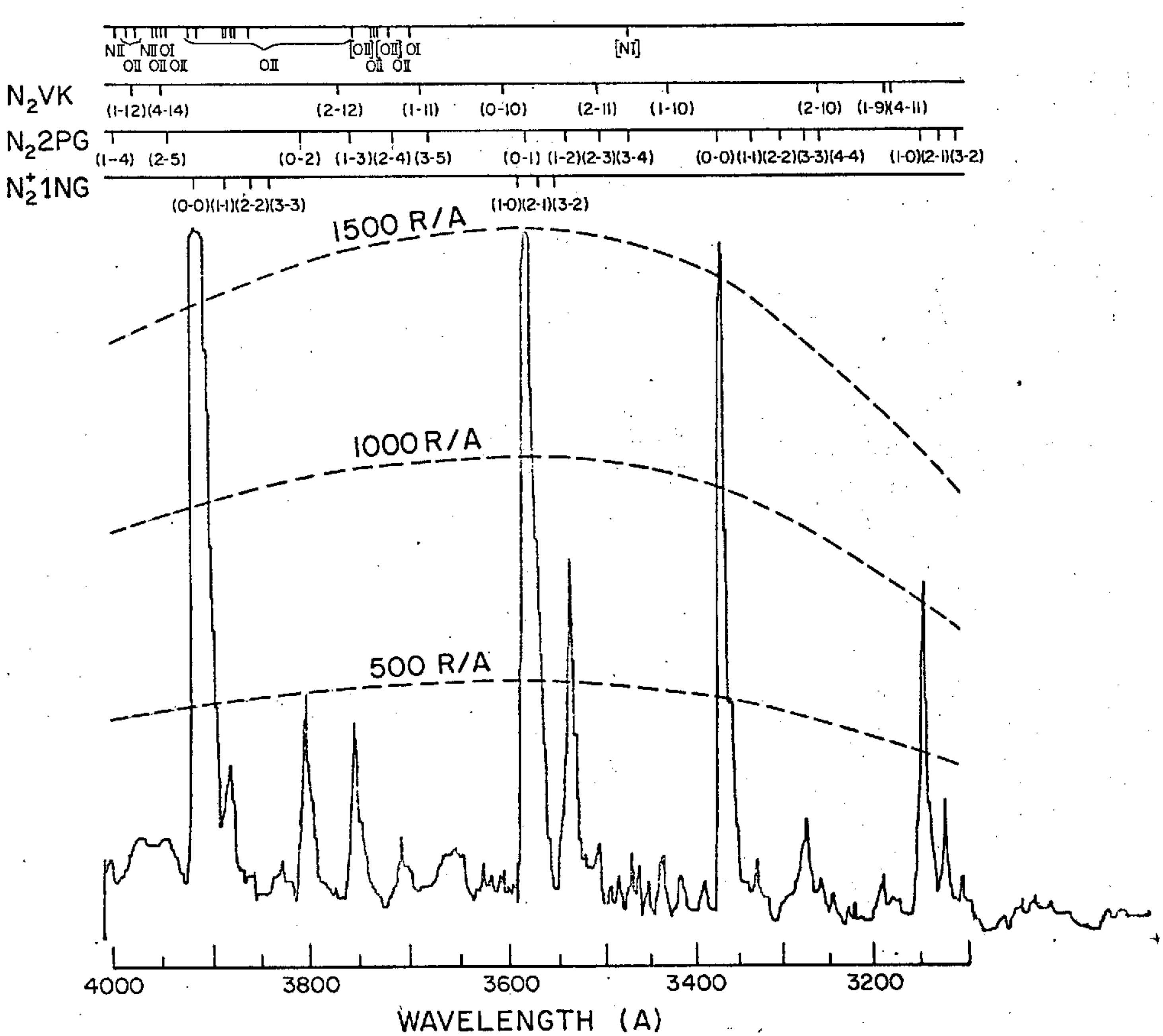

4000
3800
3600
3400
3200
WAVELENGTH (A)


12400
12600
12800
13000
13200
13400
13600
13800
FIRST ORDER WAVELENGTH (A)

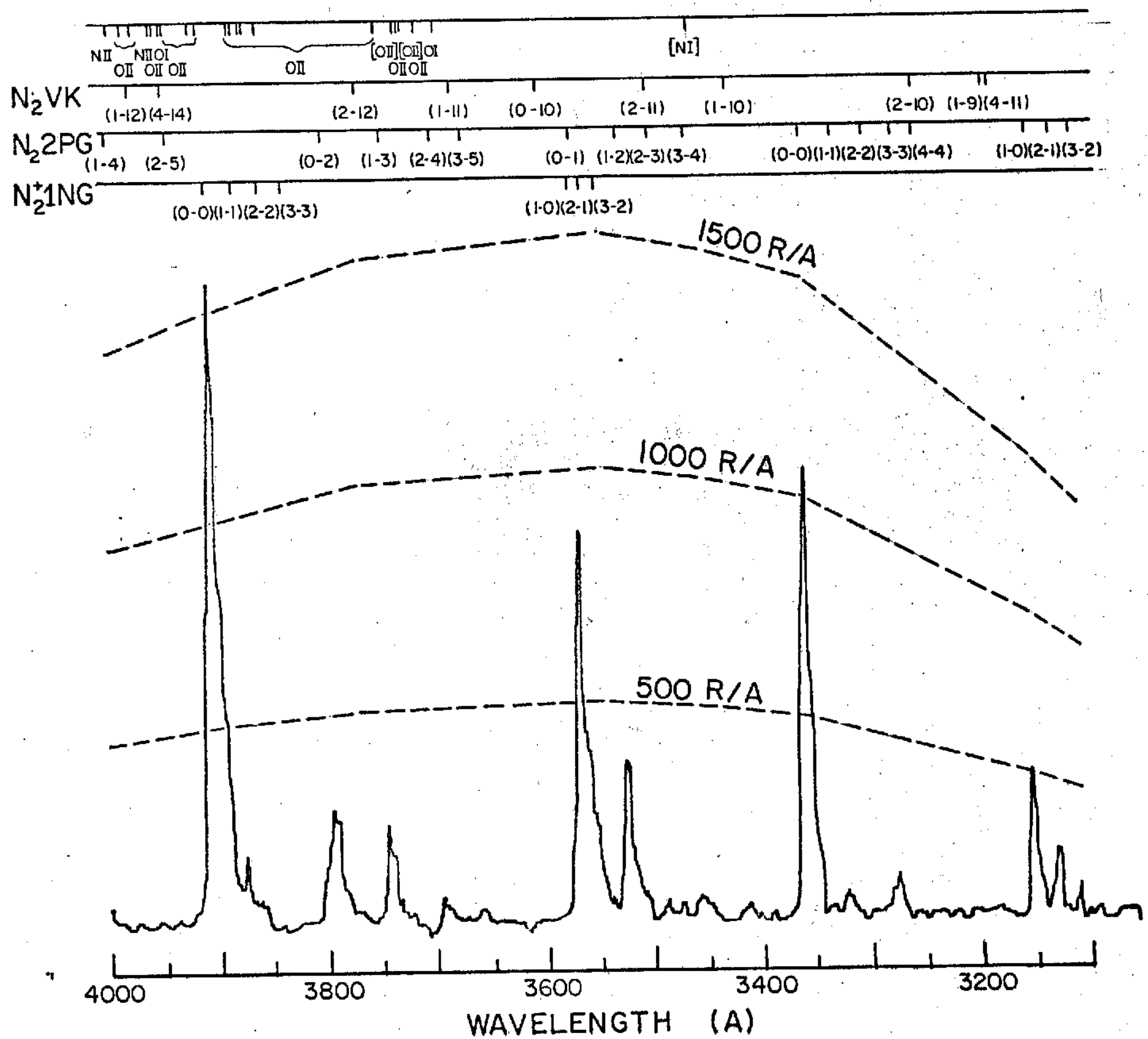


3920
3910
3900
3890
3880
3870
WAVELENGTH (A)

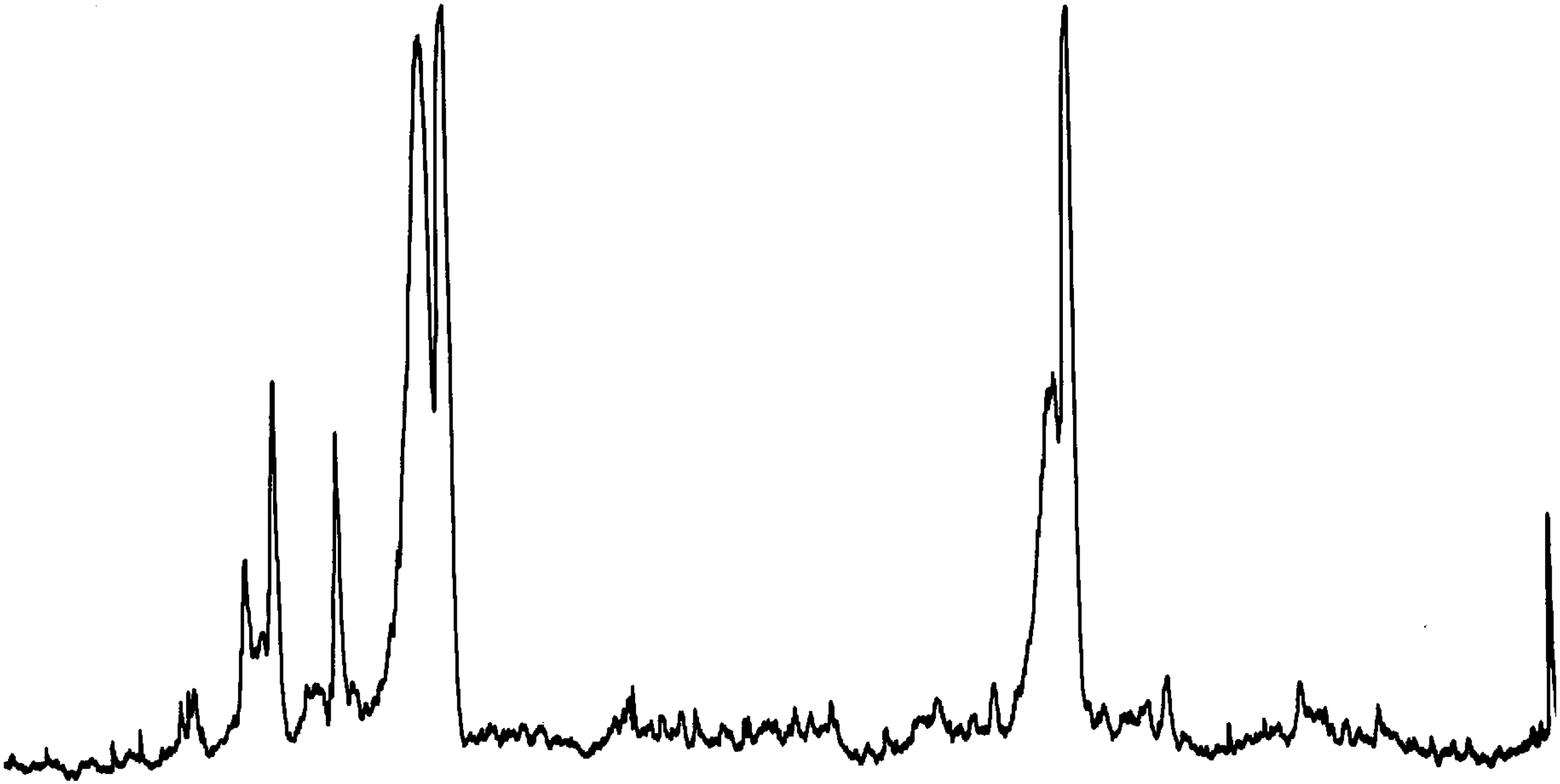

3920
3910
3900
3890
3880
3870

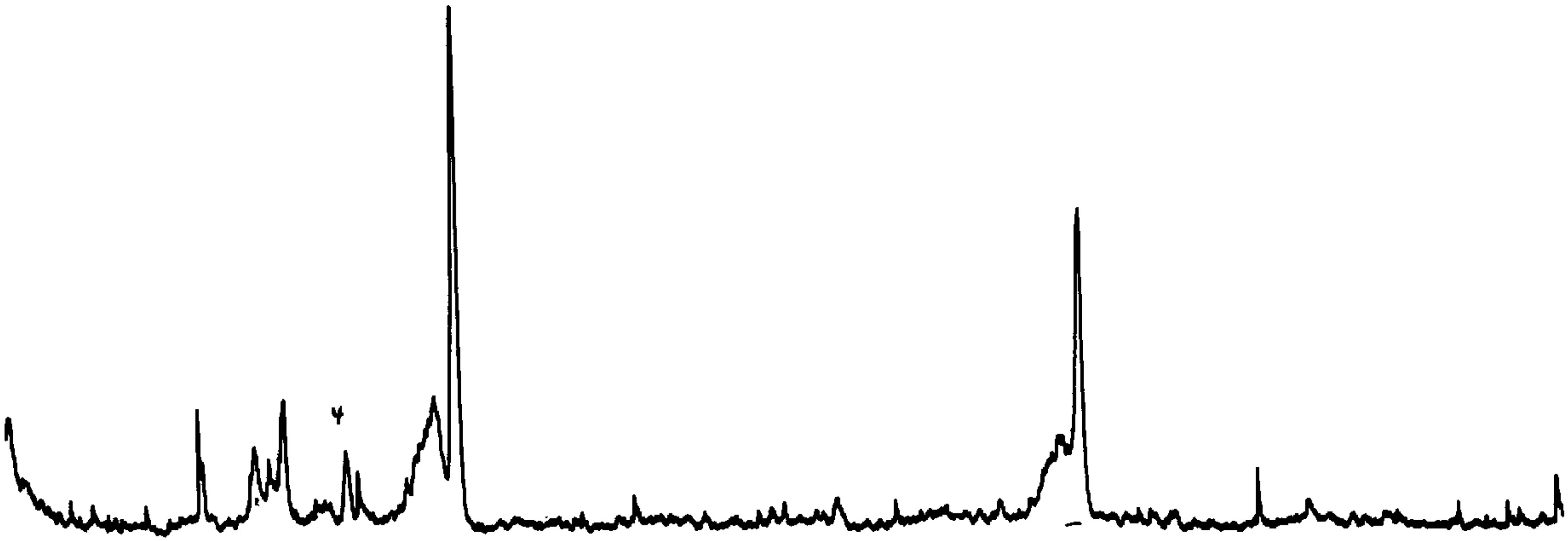


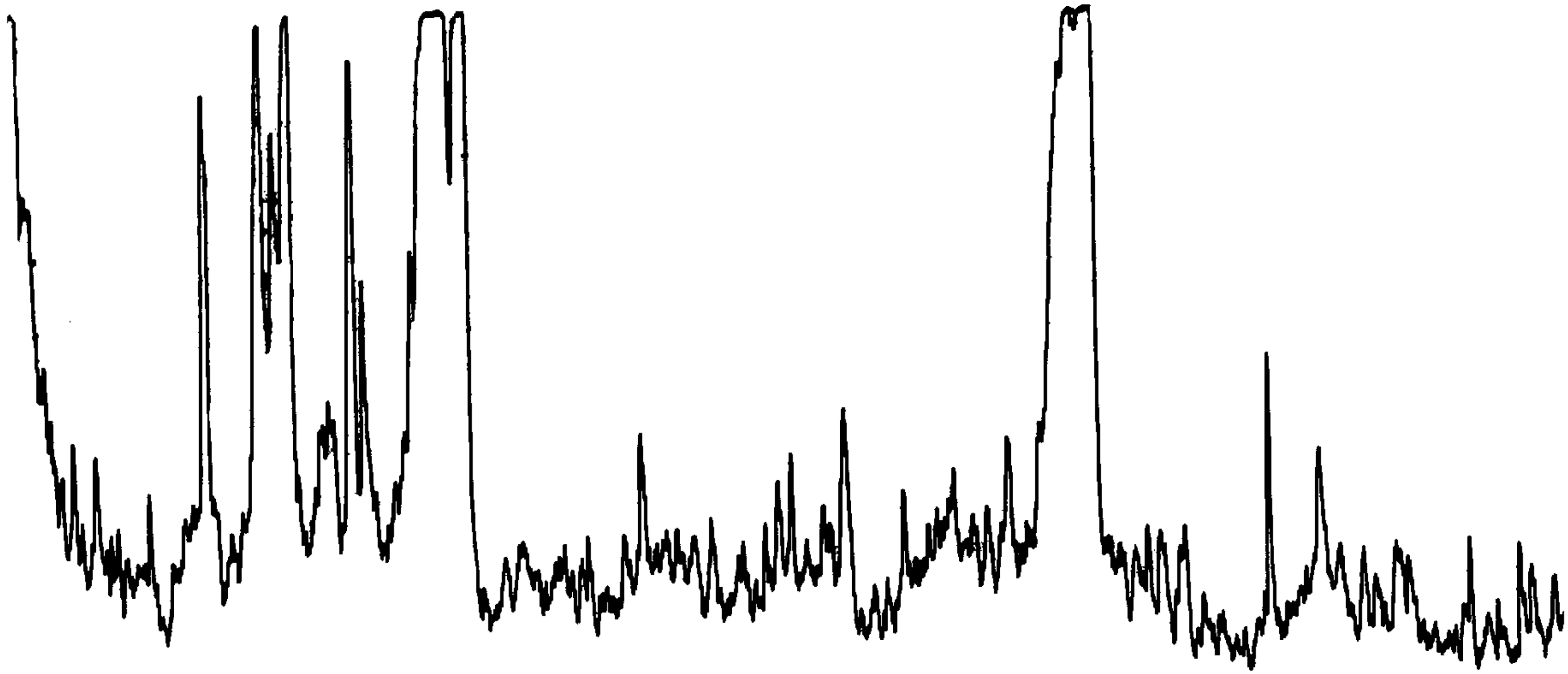
NII OII NII OII OI OII OI OII [OII] OII [OII] OII OI [NI]
N2VK
(1-12)(4-14) (2-12) (1-11) (0-10) (2-11) (1-10) (2-10) (1-9)(4-11)
N2 2PG
(1-4) (2-5) (0-2) (1-3)(2-4)(3-5) (0-1) (1-2)(2-3)(3-4) (0-0)(1-1)(2-2)(3-3)(4-4) (1-0)(2-1)(3-2)
N2+ 1NG
(0-0)(1-1)(2-2)(3-3) (1-0)(2-1)(3-2)
1500 R/A
1000 R/A
500 R/A
4000
3800
3600
3400
3200
WAVELENGTH (A)

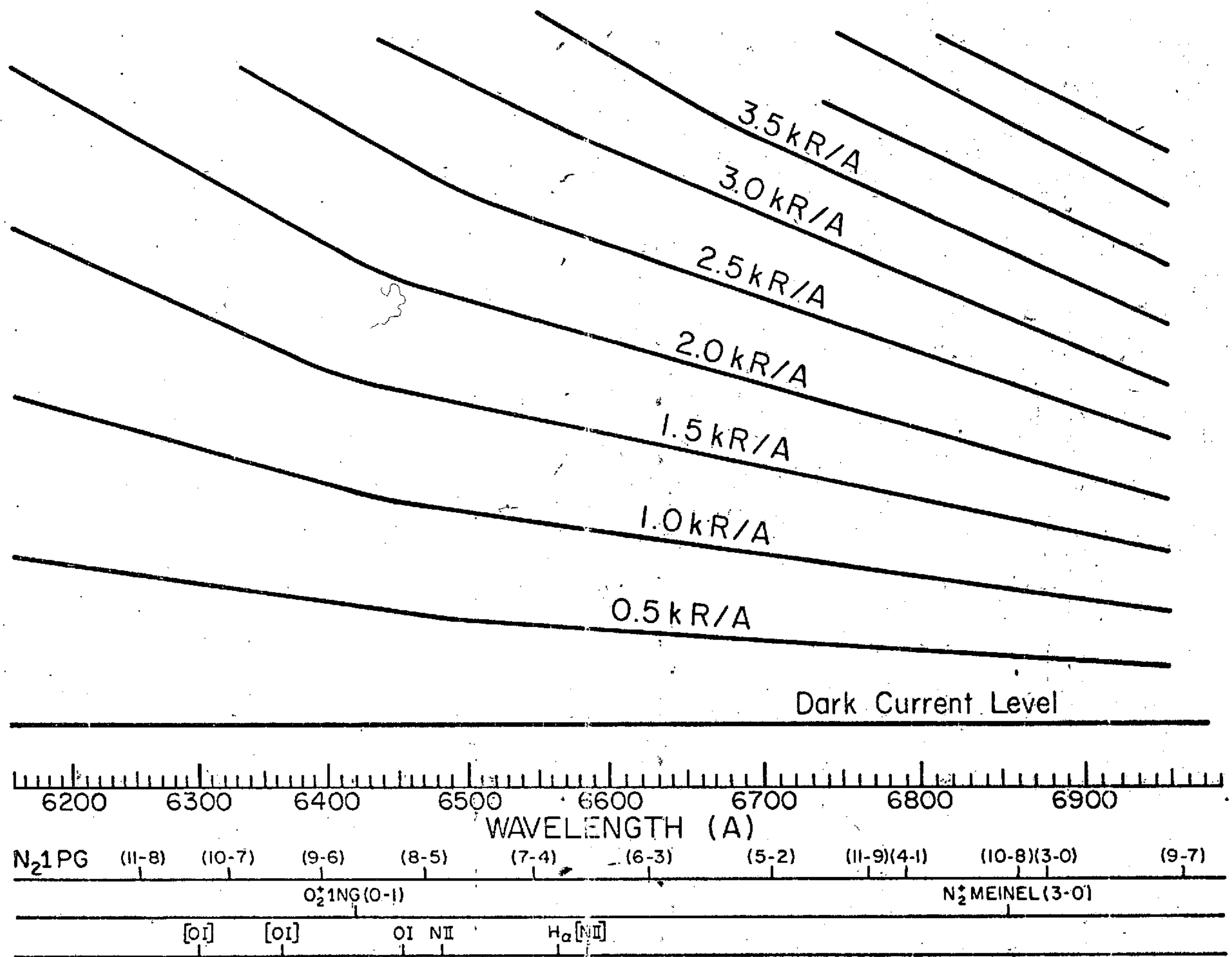


NII OII NIIOI OII OII OII [OII][OII]OI OIIOII [NI]
N_2VK
(1-12)(4-14) (2-12) (1-11) (0-10) (2-11) (1-10) (2-10) (1-9)(4-11)
$N_2$2PG
(1-4) (2-5) (0-2) (1-3) (2-4)(3-5) (0-1) (1-2)(2-3)(3-4) (0-0)(1-1)(2-2)(3-3)(4-4) (1-0)(2-1)(3-2)
N_2^+1NG
(0-0)(1-1)(2-2)(3-3) (1-0)(2-1)(3-2)
1500 R/A
1000 R/A
500 R/A
4000
3800
3600
3400
3200
WAVELENGTH (A)

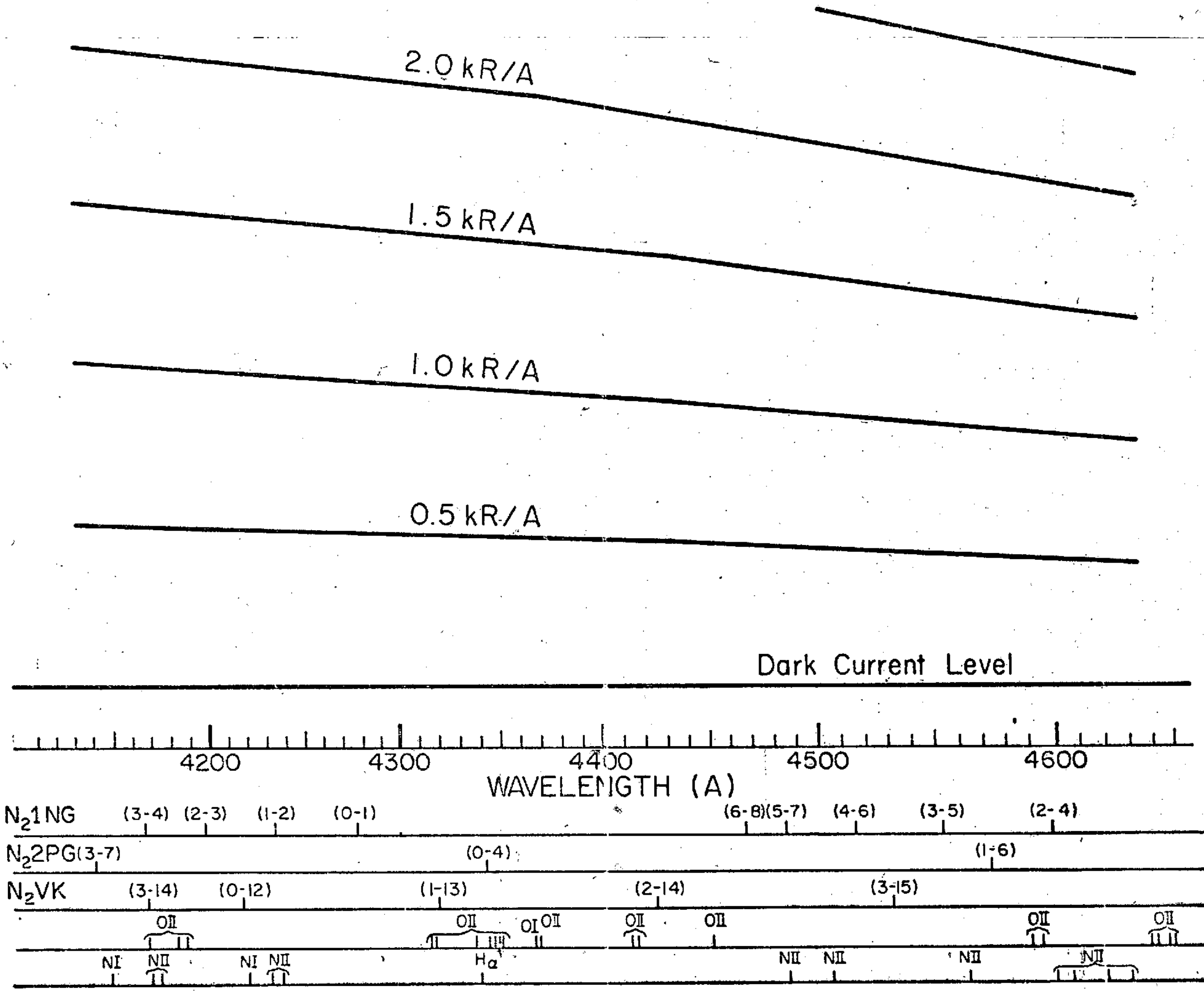



4

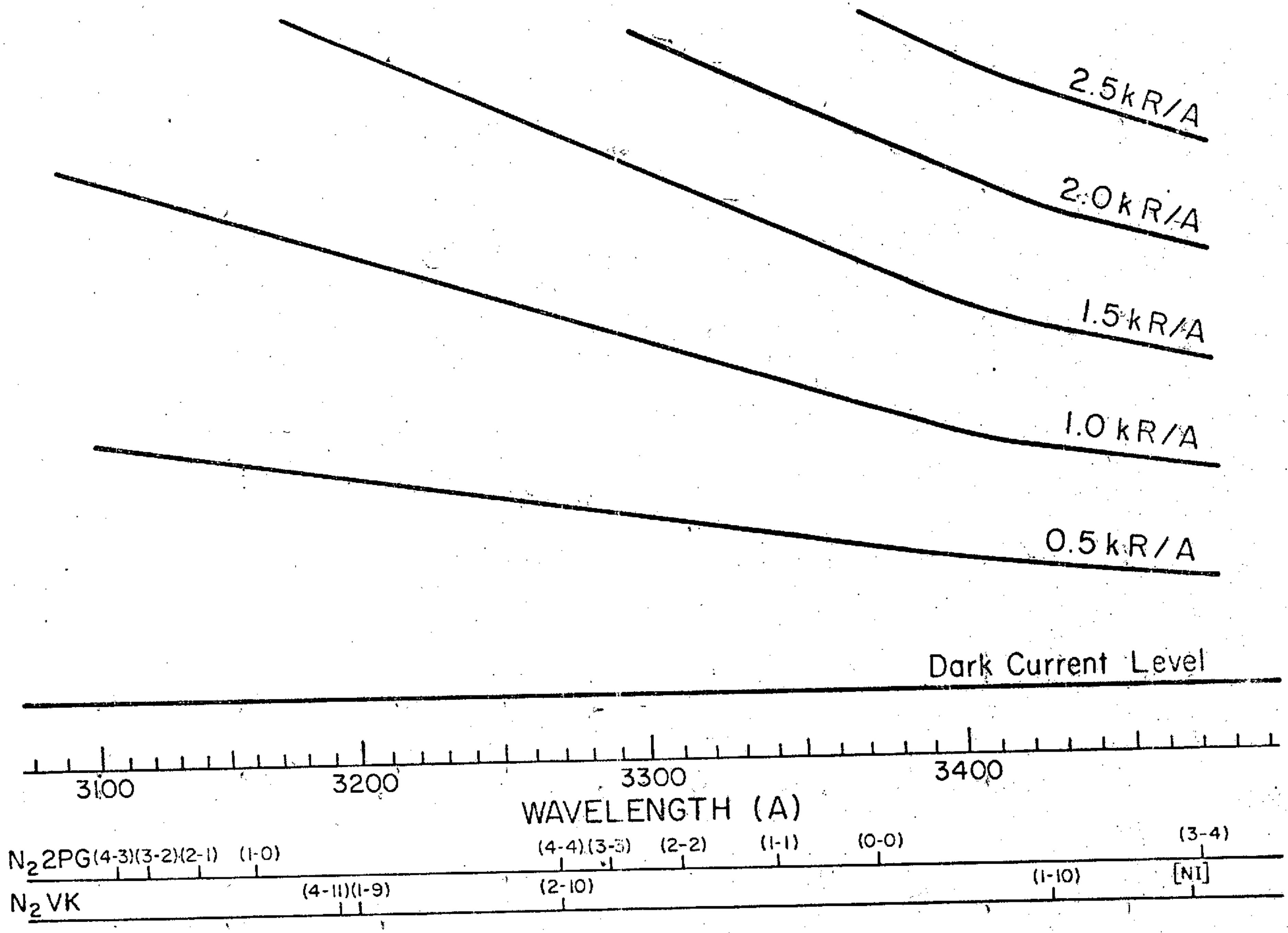




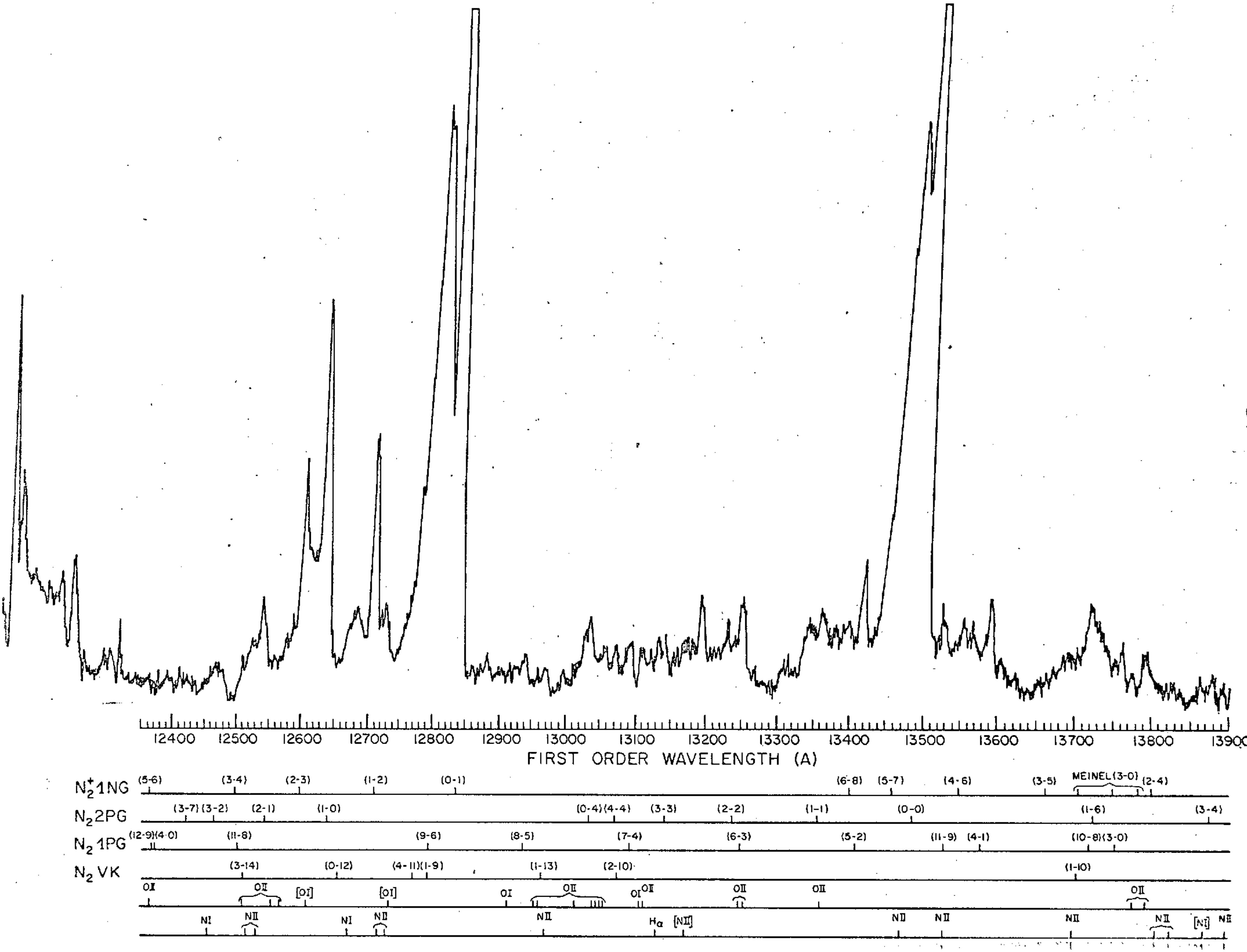
3.5 kR/A
3.0 kR/A
2.5 kR/A
2.0 kR/A
1.5 kR/A
1.0 kR/A
0.5 kR/A
Dark Current Level
6200
6300
6400
6500
6600
6700
6800
6900
WAVELENGTH (A)
N2 1PG
(11-8)
(10-7)
(9-6)
(8-5)
(7-4)
(6-3)
(5-2)
(11-9)(4-1)
(10-8)(3-0)
(9-7)
O2+ 1NG (0-1)
N2+ MEINEL (3-0)
[OI]
[OI]
OI
NII
Hα
[NII]

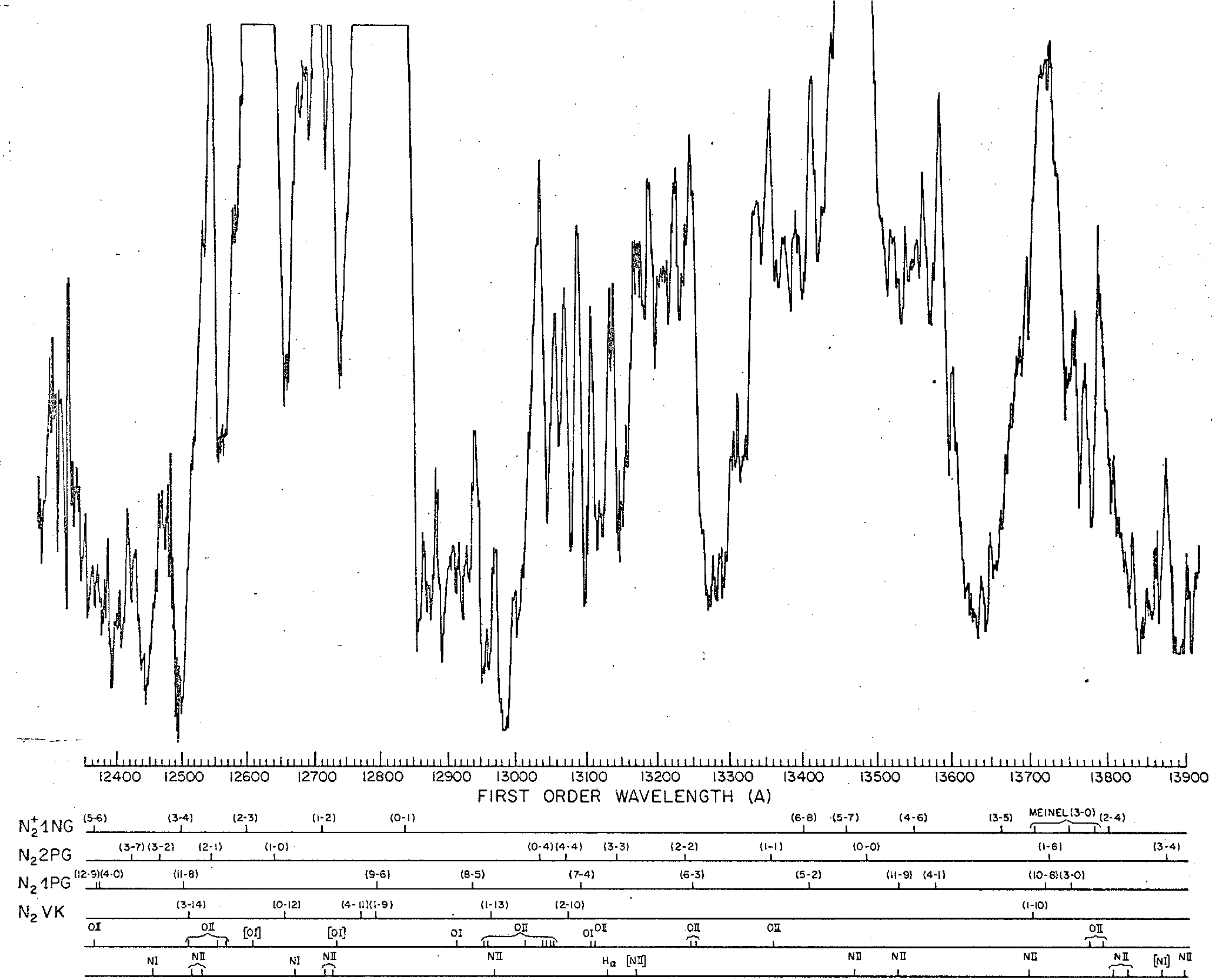


2.0 kR/A
1.5 kR/A
1.0 kR/A
0.5 kR/A
Dark Current Level
4200
4300
4400
4500
4600
WAVELENGTH (A)
N2 1NG (3-4) (2-3) (1-2) (0-1) (6-8)(5-7) (4-6) (3-5) (2-4)
N2 2PG (3-7) (0-4) (1-6)
N2 VK (3-14) (0-12) (1-13) (2-14) (3-15)
OII OII OI OII OII OII OII OII
NI NII NI NII Hα NII NII NII NII



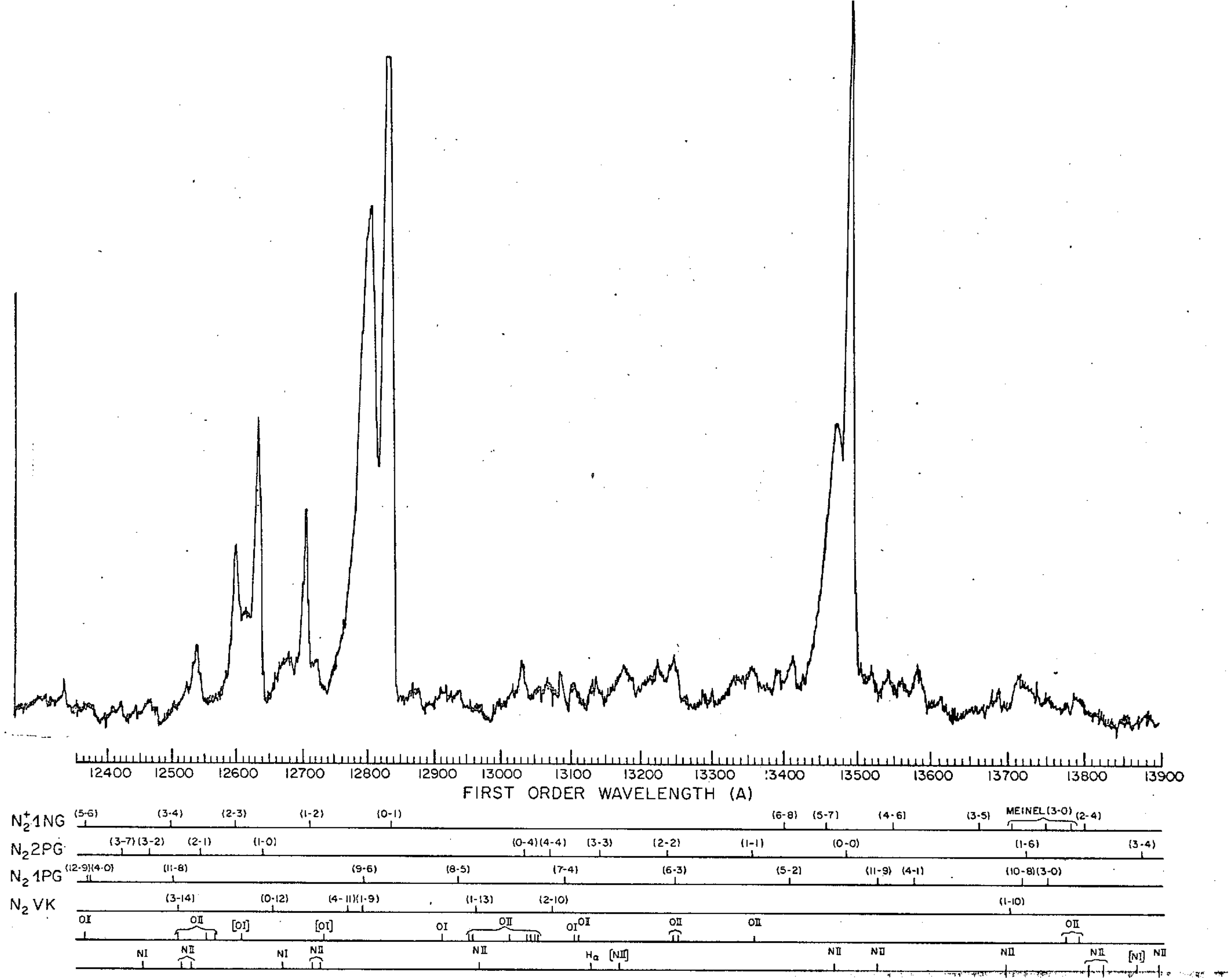
2.5 kR/A
2.0 kR/A
1.5 kR/A
1.0 kR/A
0.5 kR/A
Dark Current Level
3100
3200
3300
3400
WAVELENGTH (A)
N2 2PG (4-3)(3-2)(2-1) (1-0) (4-4)(3-3) (2-2) (1-1) (0-0) (3-4)
N2 VK (4-11)(1-9) (2-10) (1-10) [NI]

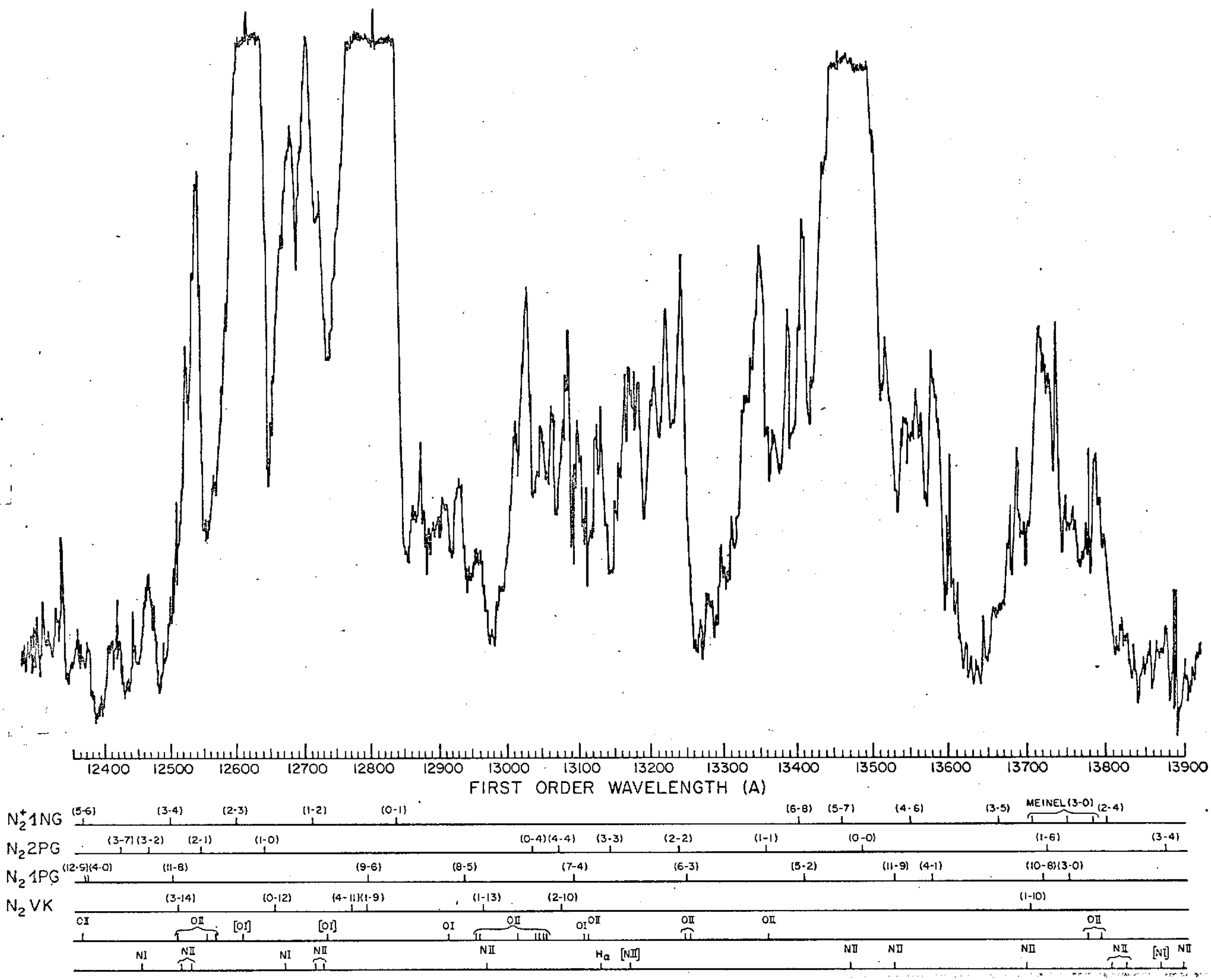

12400 12500 12600 12700 12800 12900 13000 13100 13200 13300 13400 13500 13600 13700 13800 13900
FIRST ORDER WAVELENGTH (A)
N_2^+ 1NG
(5-6) (3-4) (2-3) (1-2) (0-1) (6-8) (5-7) (4-6) (3-5) MEINEL (3-0) (2-4)
N_2 2PG
(3-7) (3-2) (2-1) (1-0) (0-4) (4-4) (3-3) (2-2) (1-1) (0-0) (1-6) (3-4)
N_2 1PG
(12-9) (4-0) (11-8) (9-6) (8-5) (7-4) (6-3) (5-2) (11-9) (4-1) (10-8) (3-0)
N_2 VK
(3-14) (0-12) (4-11) (1-9) (1-13) (2-10) (1-10)
OI OII [OI] [OI] OI OII OI OII OII OII OII
NI NII NI NII NII Hα [NII] NII NII NII NII [NI] NII



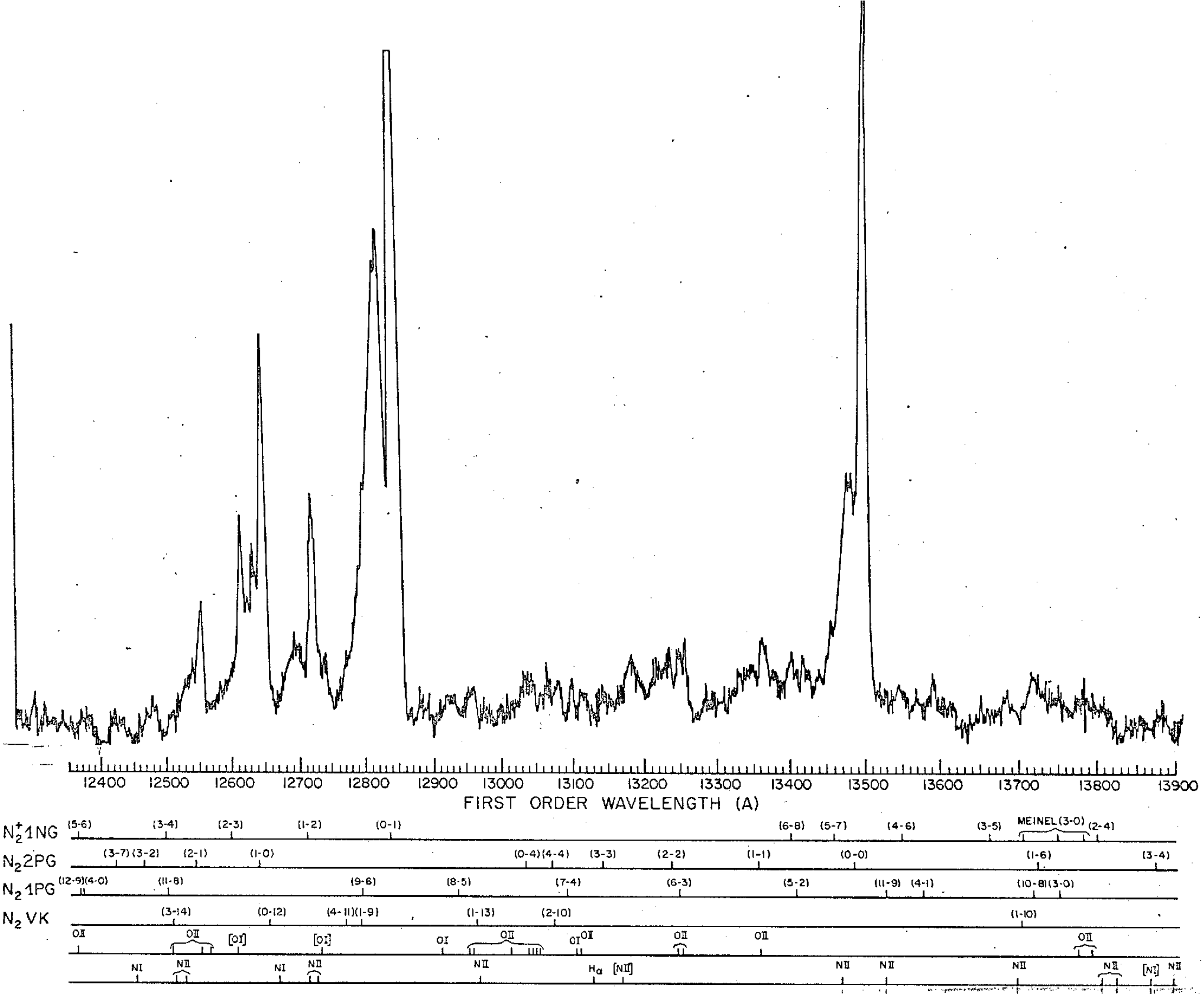
12400 12500 12600 12700 12800 12900 13000 13100 13200 13300 13400 13500 13600 13700 13800 13900
FIRST ORDER WAVELENGTH (A)
N$_2^+$1NG (5-6) (3-4) (2-3) (1-2) (0-1) (6-8) (5-7) (4-6) (3-5) MEINEL (3-0) (2-4)
N$_2$2PG (3-7) (3-2) (2-1) (1-0) (0-4) (4-4) (3-3) (2-2) (1-1) (0-0) (1-6) (3-4)
N$_2$1PG (12-9) (4-0) (11-8) (9-6) (8-5) (7-4) (6-3) (5-2) (11-9) (4-1) (10-8) (3-0)
N$_2$VK (3-14) (0-12) (4-11) (1-9) (1-13) (2-10) (1-10)
OII OII [OI] [OI] OI OII OI OII OII OII OII
NI NII NI NII NII Hα [NII] NII NII NII NII [NI] NII

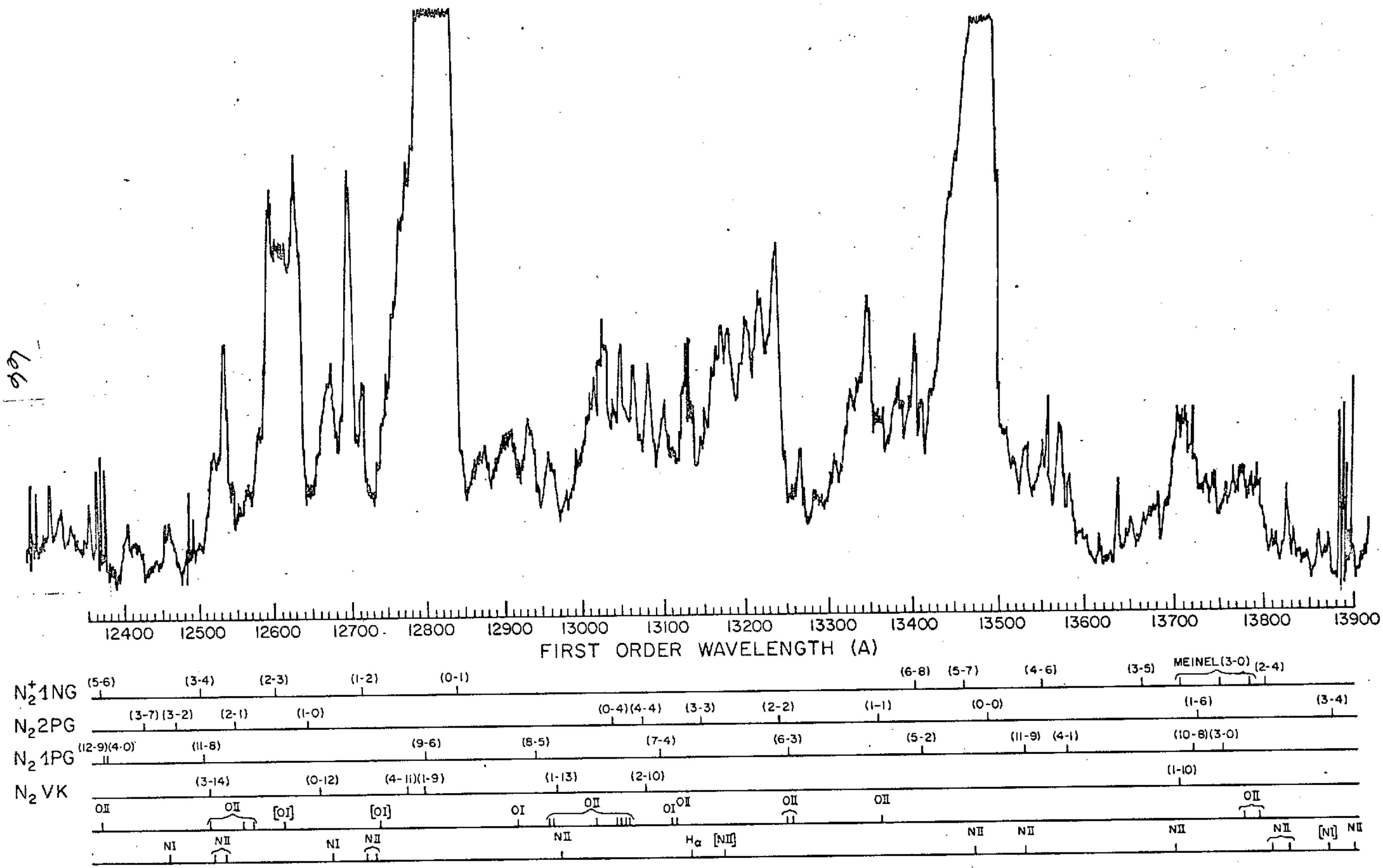
63


12400 12500 12600 12700 12800 12900 13000 13100 13200 13300 13400 13500 13600 13700 13800 13900
FIRST ORDER WAVELENGTH (A)
N$_2^+$ 1NG
(5-6) (3-4) (2-3) (1-2) (0-1) (6-8) (5-7) (4-6) (3-5) MEINEL (3-0) (2-4)
N$_2$ 2PG
(3-7) (3-2) (2-1) (1-0) (0-4) (4-4) (3-3) (2-2) (1-1) (0-0) (1-6) (3-4)
N$_2$ 1PG
(12-9) (4-0) (11-8) (9-6) (8-5) (7-4) (6-3) (5-2) (11-9) (4-1) (10-8) (3-0)
N$_2$ VK
(3-14) (0-12) (4-11) (1-9) (1-13) (2-10) (1-10)
OI OII [OI] [OI] OI OII OI OI OII OII OII
NI NII NI NII NII Hα [NII] NII NII NII NII [NI] NII

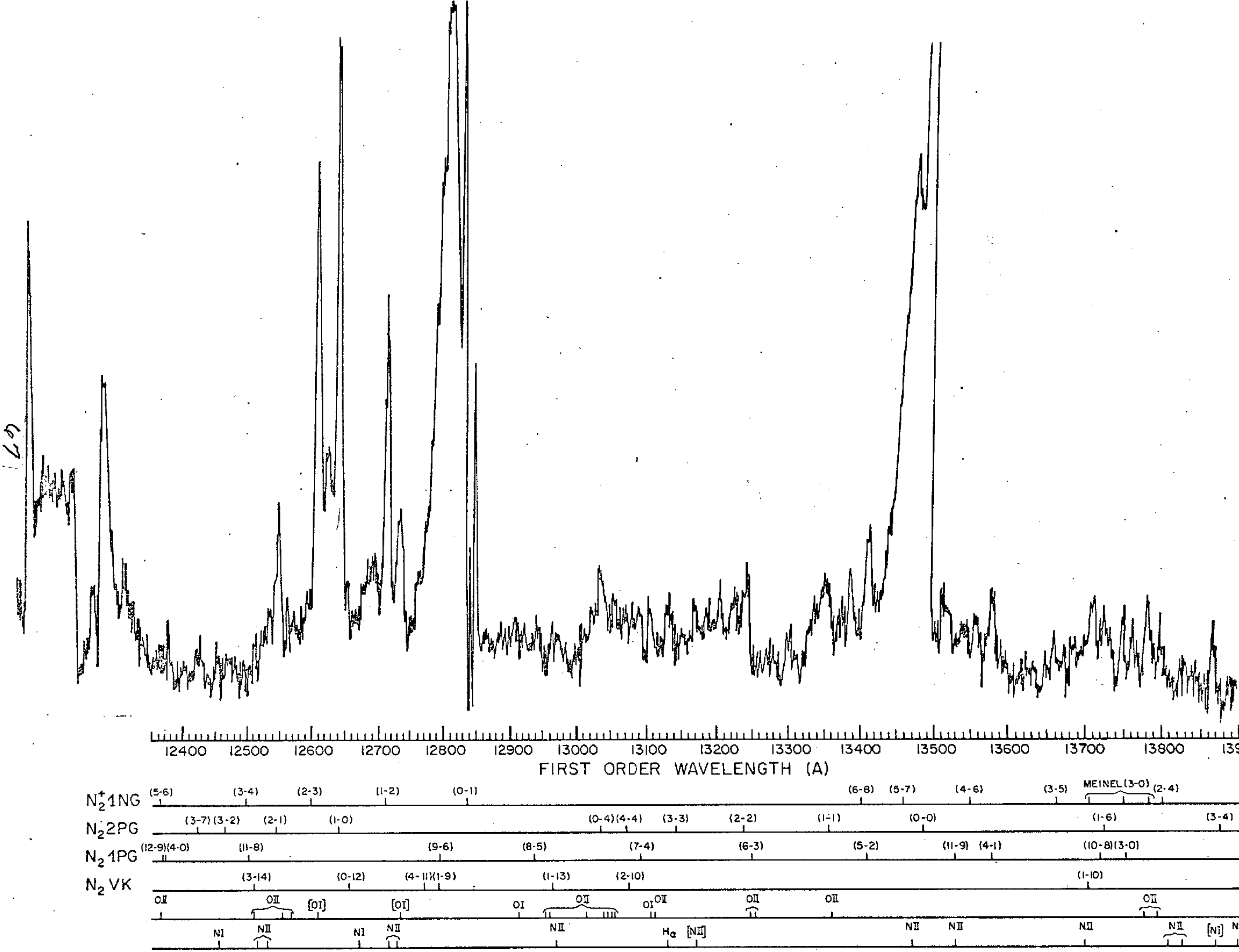


12400 12500 12600 12700 12800 12900 13000 13100 13200 13300 13400 13500 13600 13700 13800 13900
FIRST ORDER WAVELENGTH (A)
N_2^+ 1NG
(5-6) (3-4) (2-3) (1-2) (0-1) (6-8) (5-7) (4-6) (3-5) MEINEL (3-0) (2-4)
N_2 2PG
(3-7) (3-2) (2-1) (1-0) (0-4) (4-4) (3-3) (2-2) (1-1) (0-0) (1-6) (3-4)
N_2 1PG
(12-9) (4-0) (11-8) (9-6) (8-5) (7-4) (6-3) (5-2) (11-9) (4-1) (10-8) (3-0)
N_2 VK
(3-14) (0-12) (4-11) (1-9) (1-13) (2-10) (1-10)
OI OII [OI] [OI] OI OII OI OII OII OII OII
NI NII NI NII NII H_α [NII] NII NII NII NII [NI] NII

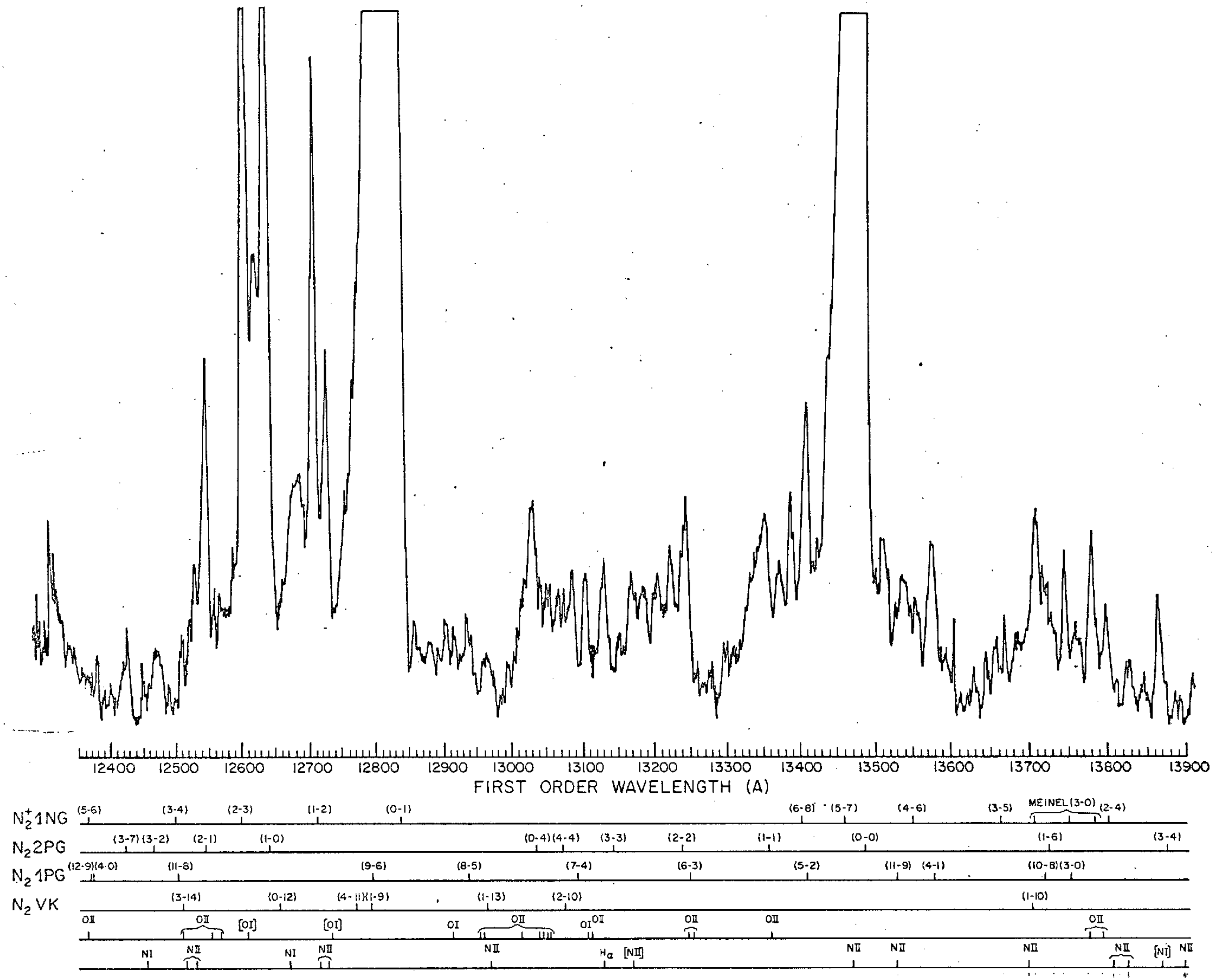

12400 12500 12600 12700 12800 12900 13000 13100 13200 13300 13400 13500 13600 13700 13800 13900
FIRST ORDER WAVELENGTH (A)
N2+ 1NG (5-6) (3-4) (2-3) (1-2) (0-1) (6-8) (5-7) (4-6) (3-5) MEINEL (3-0) (2-4)
N2 2PG (3-7) (3-2) (2-1) (1-0) (0-4) (4-4) (3-3) (2-2) (1-1) (0-0) (1-6) (3-4)
N2 1PG (12-9)(4-0) (11-8) (9-6) (8-5) (7-4) (6-3) (5-2) (11-9) (4-1) (10-8)(3-0)
N2 VK (3-14) (0-12) (4-11)(1-9) (1-13) (2-10) (1-10)
OII OII [OI] [OI] OI OII OI OII OII OII OII
NI NII NI NII NII Hα [NII] NII NII NII NII [NI] NII



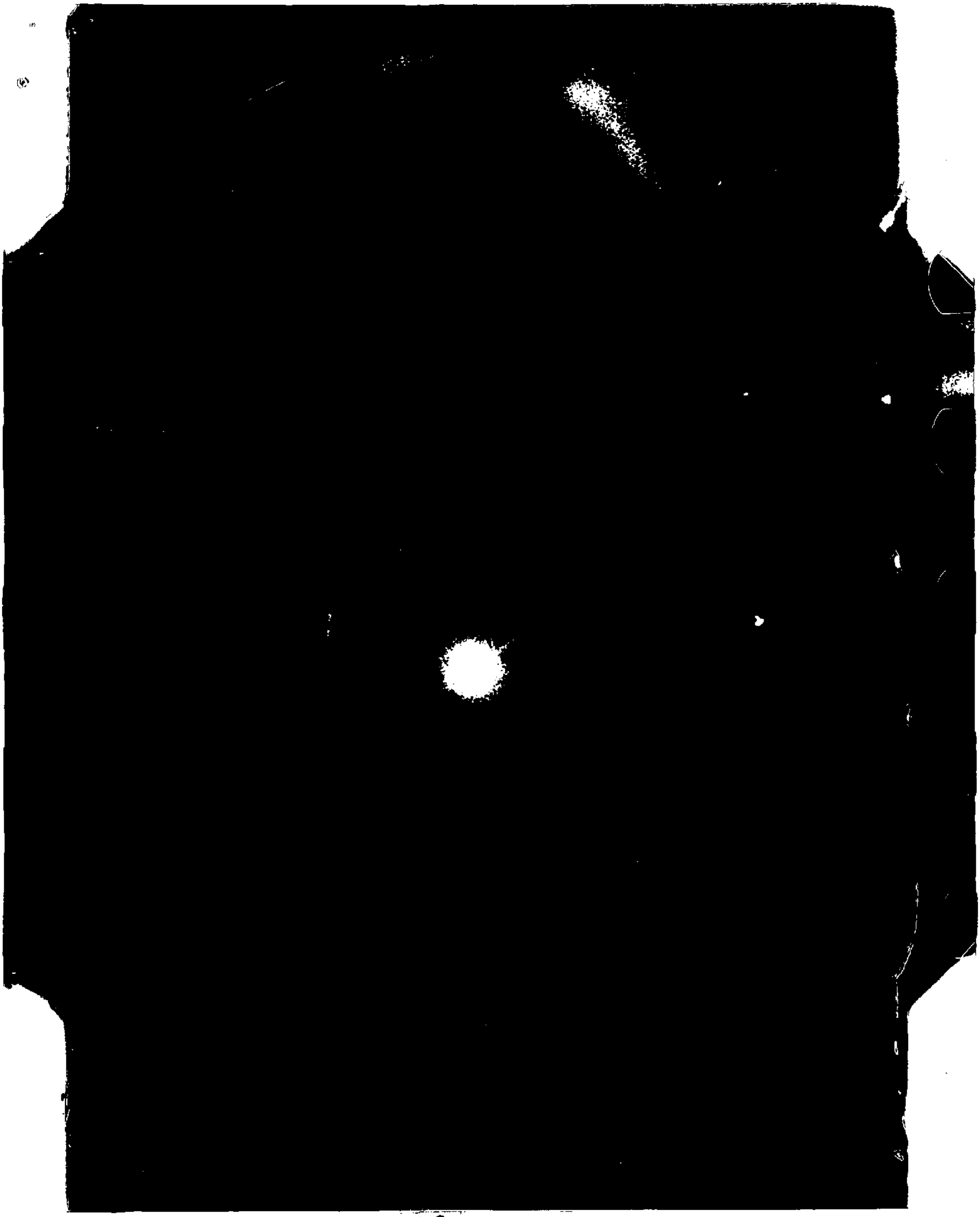
12400 12500 12600 12700 12800 12900 13000 13100 13200 13300 13400 13500 13600 13700 13800 13900
FIRST ORDER WAVELENGTH (A)
N_2^+ 1NG
(5-6) (3-4) (2-3) (1-2) (0-1) (6-8) (5-7) (4-6) (3-5) MEINEL (3-0) (2-4)
N_2 2PG
(3-7) (3-2) (2-1) (1-0) (0-4) (4-4) (3-3) (2-2) (1-1) (0-0) (1-6) (3-4)
N_2 1PG
(12-9) (4-0) (11-8) (9-6) (8-5) (7-4) (6-3) (5-2) (11-9) (4-1) (10-8) (3-0)
N_2 VK
(3-14) (0-12) (4-11) (1-9) (1-13) (2-10) (1-10)
OII OII [OI] [OI] OI OII OI OII OII OII OII
NI NII NI NII NII H_α [NII] NII NII NII NII [NI] NII



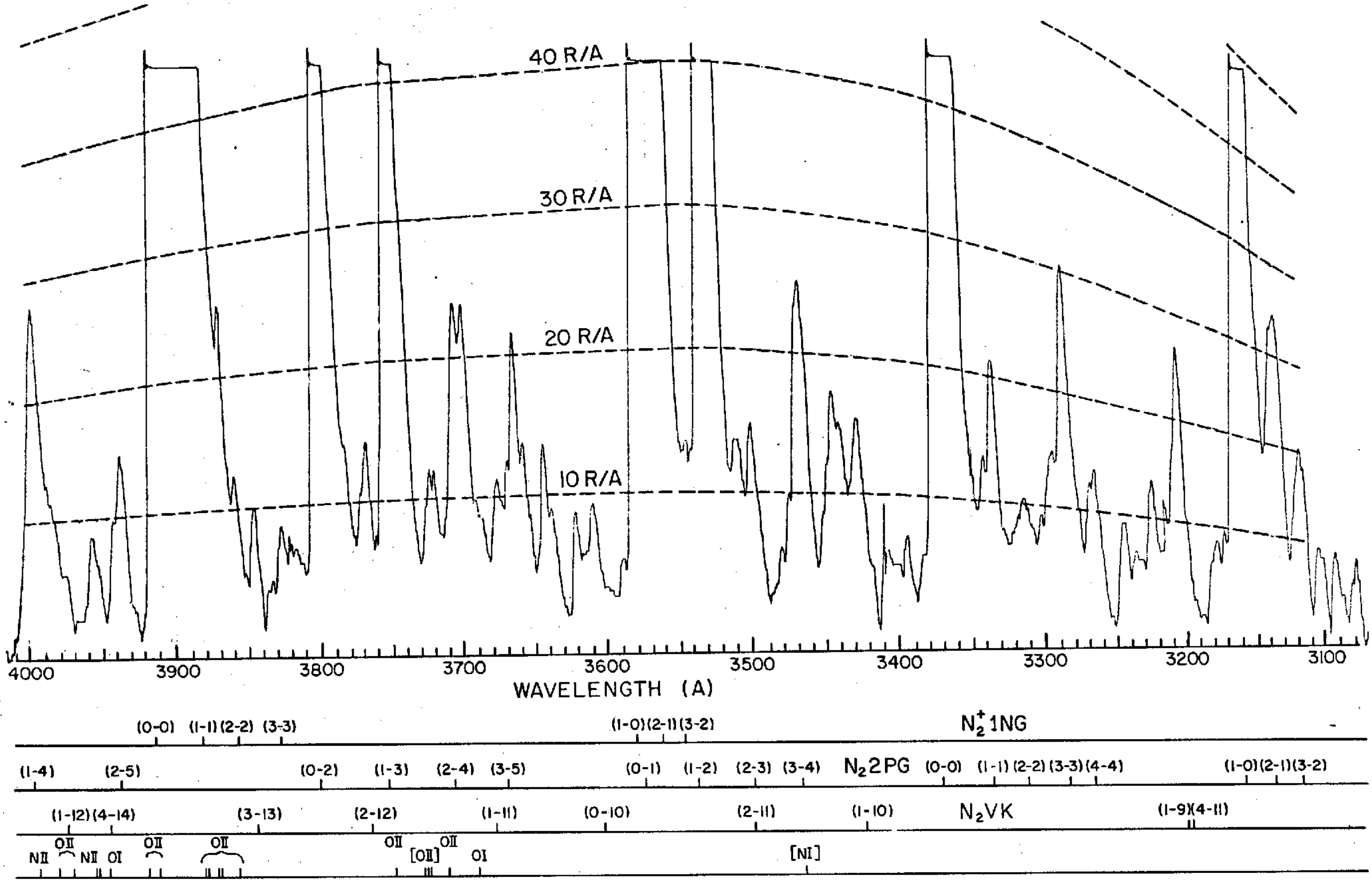
12400 12500 12600 12700 12800 12900 13000 13100 13200 13300 13400 13500 13600 13700 13800 13900
FIRST ORDER WAVELENGTH (A)
N2+ 1NG (5-6) (3-4) (2-3) (1-2) (0-1) (6-8) (5-7) (4-6) (3-5) MEINEL (3-0) (2-4)
N2 2PG (3-7) (3-2) (2-1) (1-0) (0-4) (4-4) (3-3) (2-2) (1-1) (0-0) (1-6) (3-4)
N2 1PG (12-9) (4-0) (11-8) (9-6) (8-5) (7-4) (6-3) (5-2) (11-9) (4-1) (10-8) (3-0)
N2 VK (3-14) (0-12) (4-11) (1-9) (1-13) (2-10) (1-10)
OII OII [OI] [OI] OI OII OI OII OII OII OII
NI NII NI NII NII Hα [NII] NII NII NII NII [NI] NII



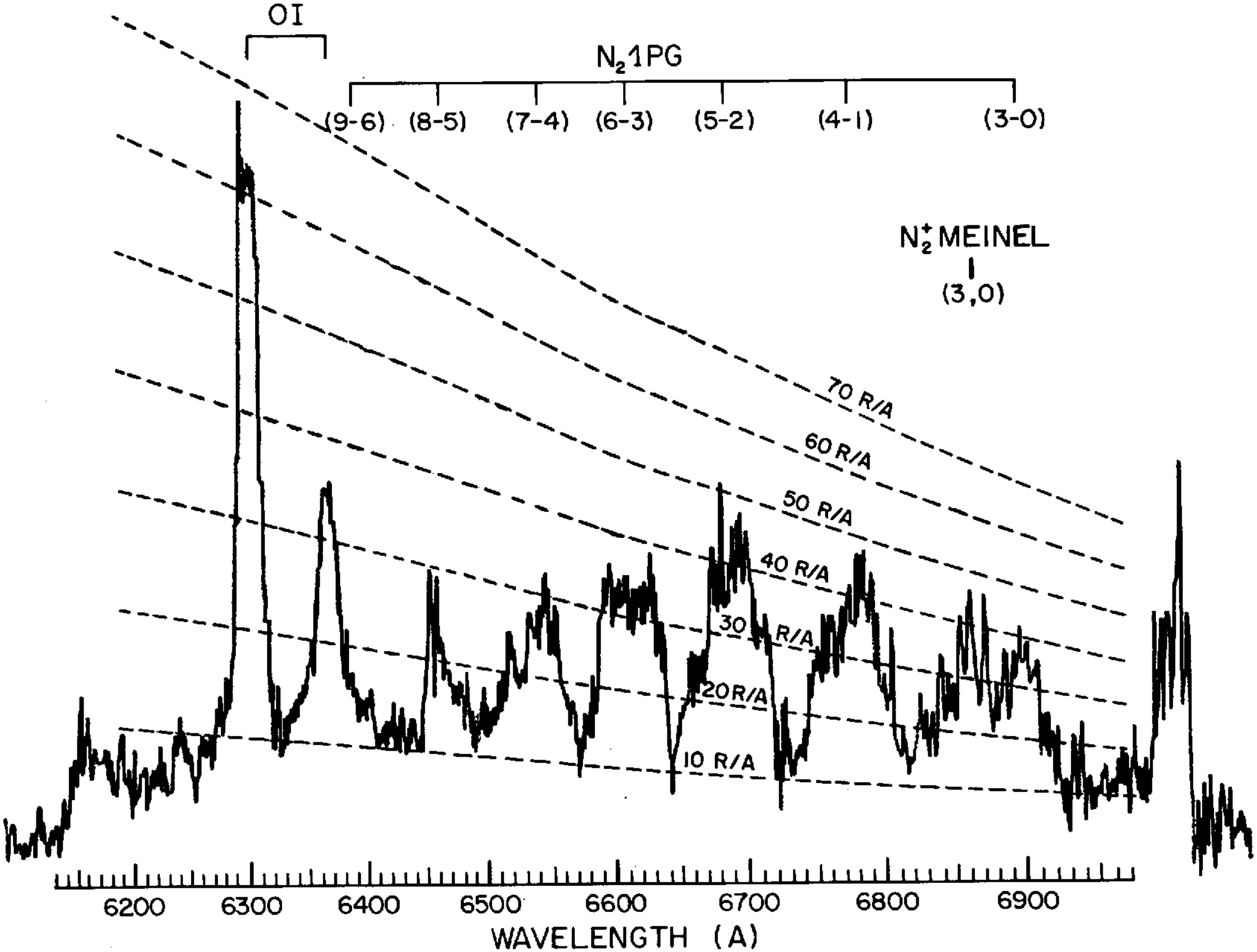
12400 12500 12600 12700 12800 12900 13000 13100 13200 13300 13400 13500 13600 13700 13800 13900
FIRST ORDER WAVELENGTH (A)
N$_2^+$ 1NG (5-6) (3-4) (2-3) (1-2) (0-1) (6-8) (5-7) (4-6) (3-5) MEINEL (3-0) (2-4)
N$_2$ 2PG (3-7) (3-2) (2-1) (1-0) (0-4) (4-4) (3-3) (2-2) (1-1) (0-0) (1-6) (3-4)
N$_2$ 1PG (12-9) (4-0) (11-8) (9-6) (8-5) (7-4) (6-3) (5-2) (11-9) (4-1) (10-8) (3-0)
N$_2$ VK (3-14) (0-12) (4-11) (1-9) (1-13) (2-10) (1-10)
OII OII [OI] [OI] OI OII OI OI OII OII OII
NI NII NI NII NII Hα [NII] NII NII NII NII [NI] NII

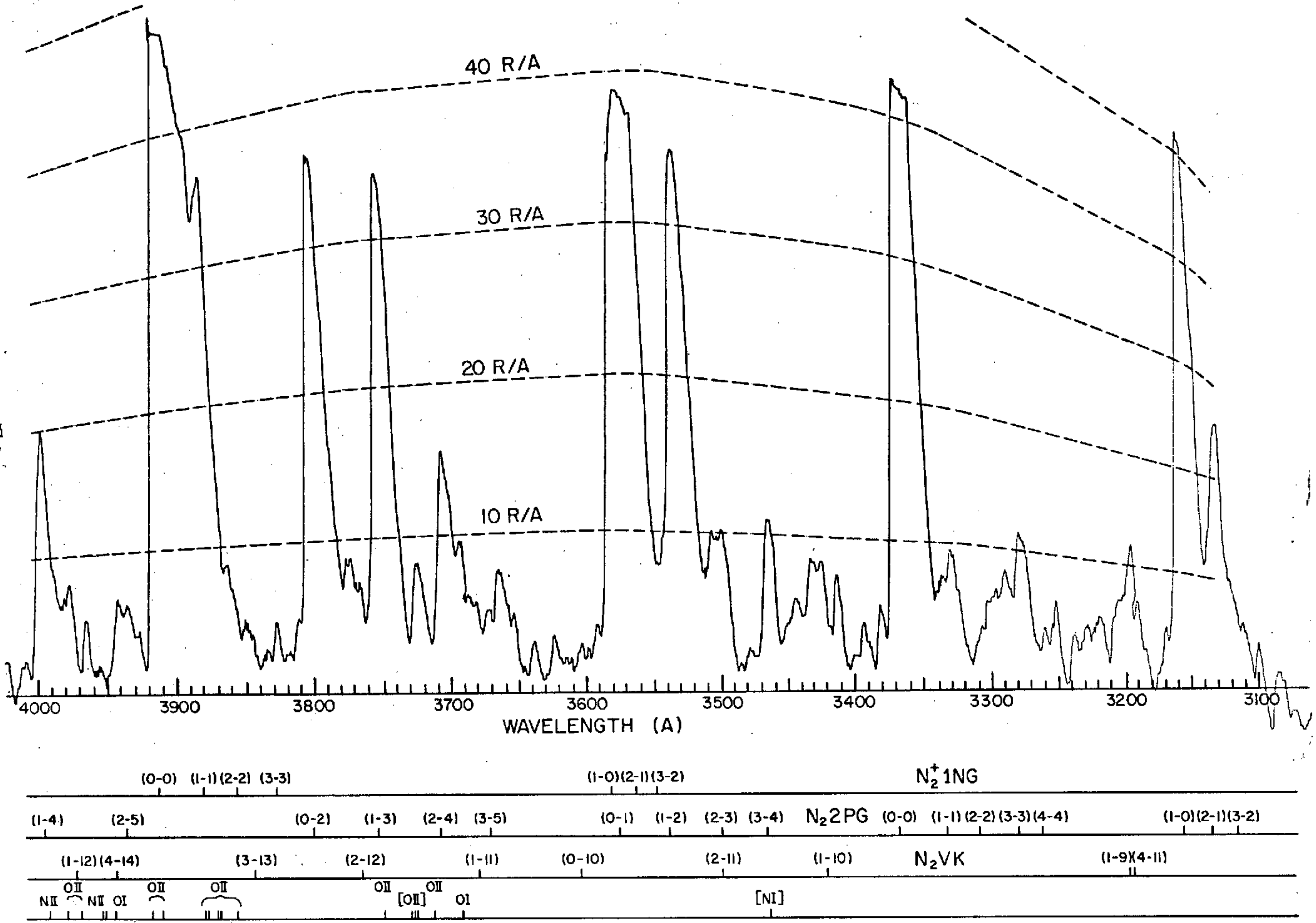


6911

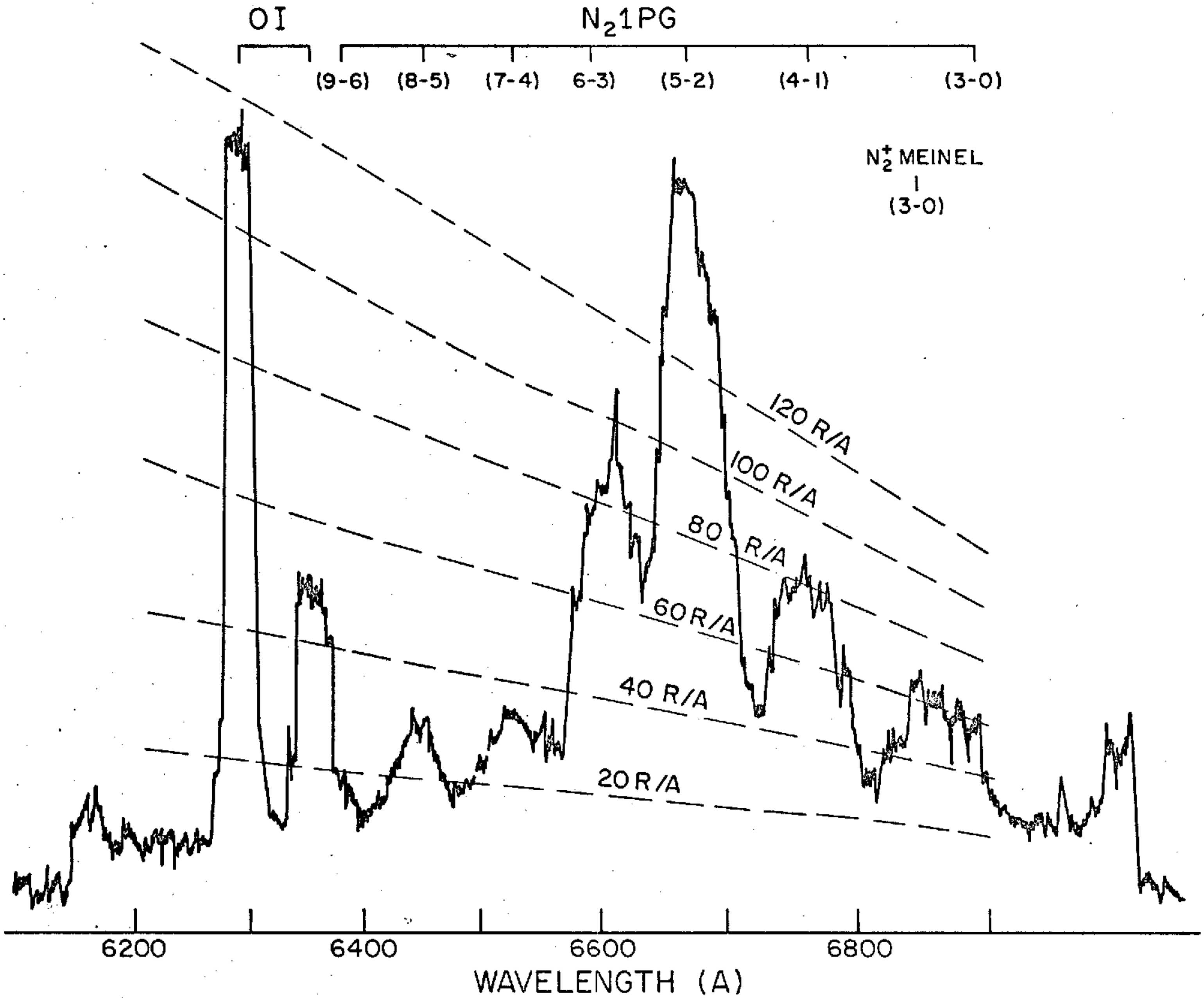


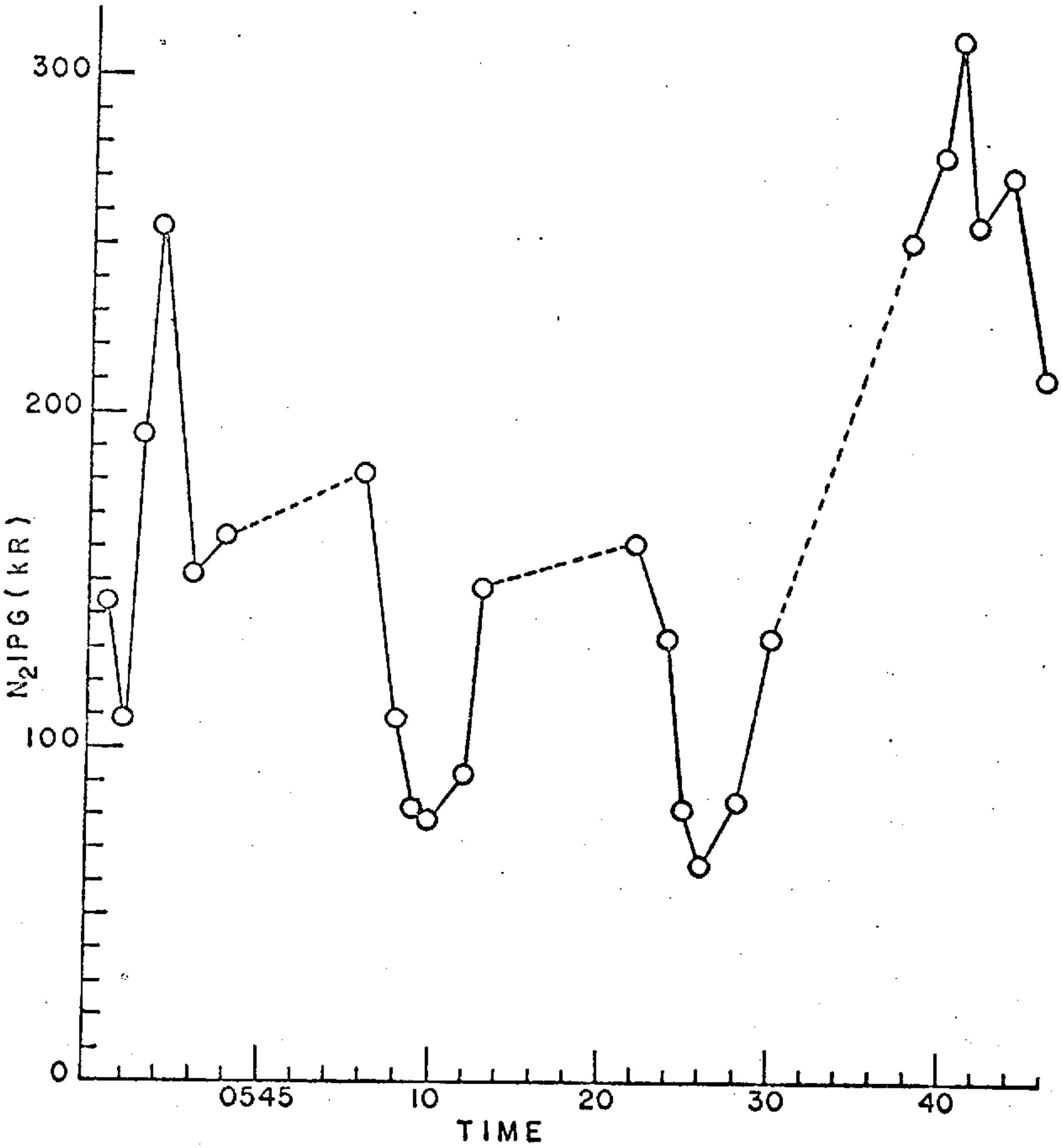
40 R/A
30 R/A
20 R/A
10 R/A
4000
3900
3800
3700
3600
3500
3400
3300
3200
3100
WAVELENGTH (A)
(0-0) (1-1) (2-2) (3-3) (1-0) (2-1) (3-2) N_2^+ 1NG
(1-4) (2-5) (0-2) (1-3) (2-4) (3-5) (0-1) (1-2) (2-3) (3-4) N_2 2PG (0-0) (1-1) (2-2) (3-3) (4-4) (1-0) (2-1) (3-2)
(1-12) (4-14) (3-13) (2-12) (1-11) (0-10) (2-11) (1-10) N_2 VK (1-9) (4-11)
NII OII NII OI OII OII OII [OII] OII OI [NI]


OI
N_2 1PG
(9-6)
(8-5)
(7-4)
(6-3)
(5-2)
(4-1)
(3-0)
N_2^+ MEINEL
(3,0)
70 R/A
60 R/A
50 R/A
40 R/A
30 R/A
20 R/A
10 R/A
6200
6300
6400
6500
6600
6700
6800
6900
WAVELENGTH (A)

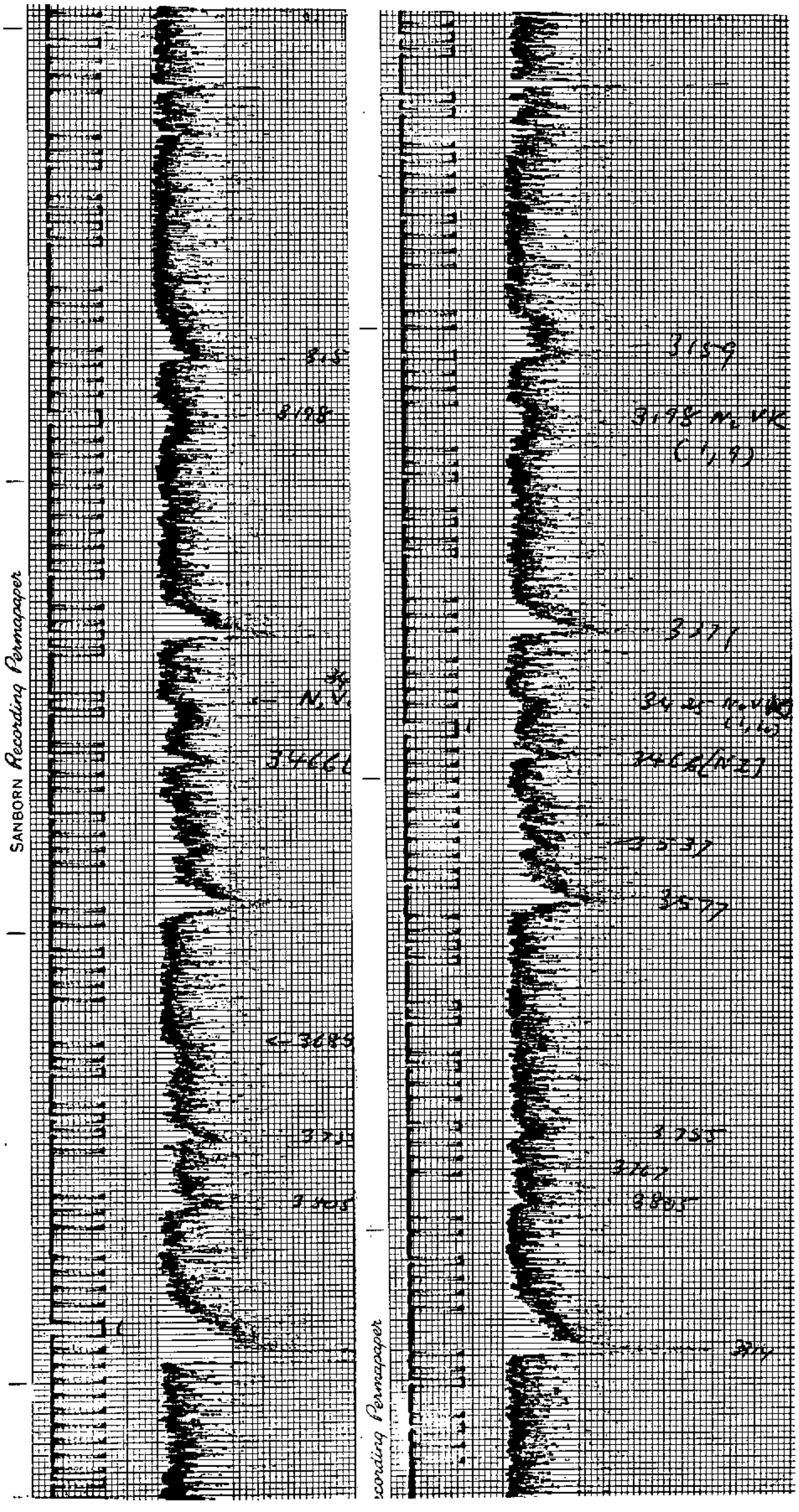


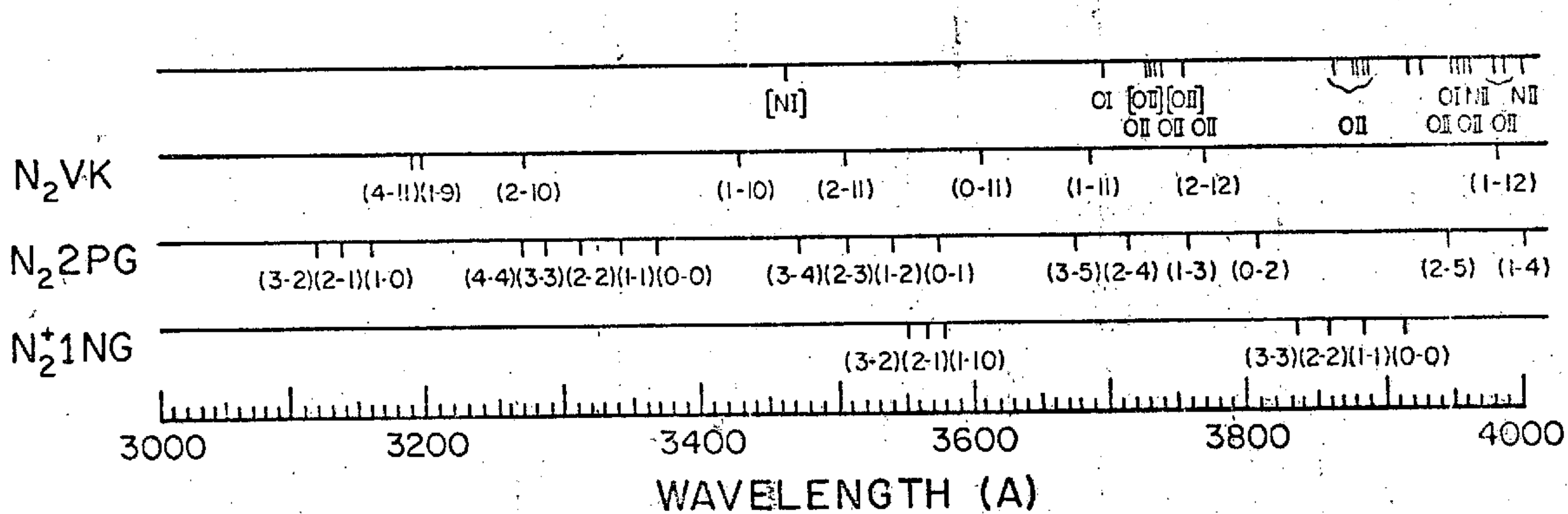
40 R/A
30 R/A
20 R/A
10 R/A
4000
3900
3800
3700
3600
3500
3400
3300
3200
3100
WAVELENGTH (A)
(0-0) (1-1) (2-2) (3-3)
(1-0) (2-1) (3-2)
N_2^+ 1NG
(1-4) (2-5) (0-2) (1-3) (2-4) (3-5) (0-1) (1-2) (2-3) (3-4)
N_2 2PG
(0-0) (1-1) (2-2) (3-3) (4-4) (1-0) (2-1) (3-2)
(1-12) (4-14) (3-13) (2-12) (1-11) (0-10) (2-11) (1-10)
N_2 VK
(1-9)(4-11)
NII OII NII OI OII OII OII [OII] OII OI [NI]


OI
N_2 1PG
(9-6)
(8-5)
(7-4)
6-3)
(5-2)
(4-1)
(3-0)
N_2^+ MEINEL
(3-0)
120 R/A
100 R/A
80 R/A
60 R/A
40 R/A
20 R/A
6200
6400
6600
6800
WAVELENGTH (A)



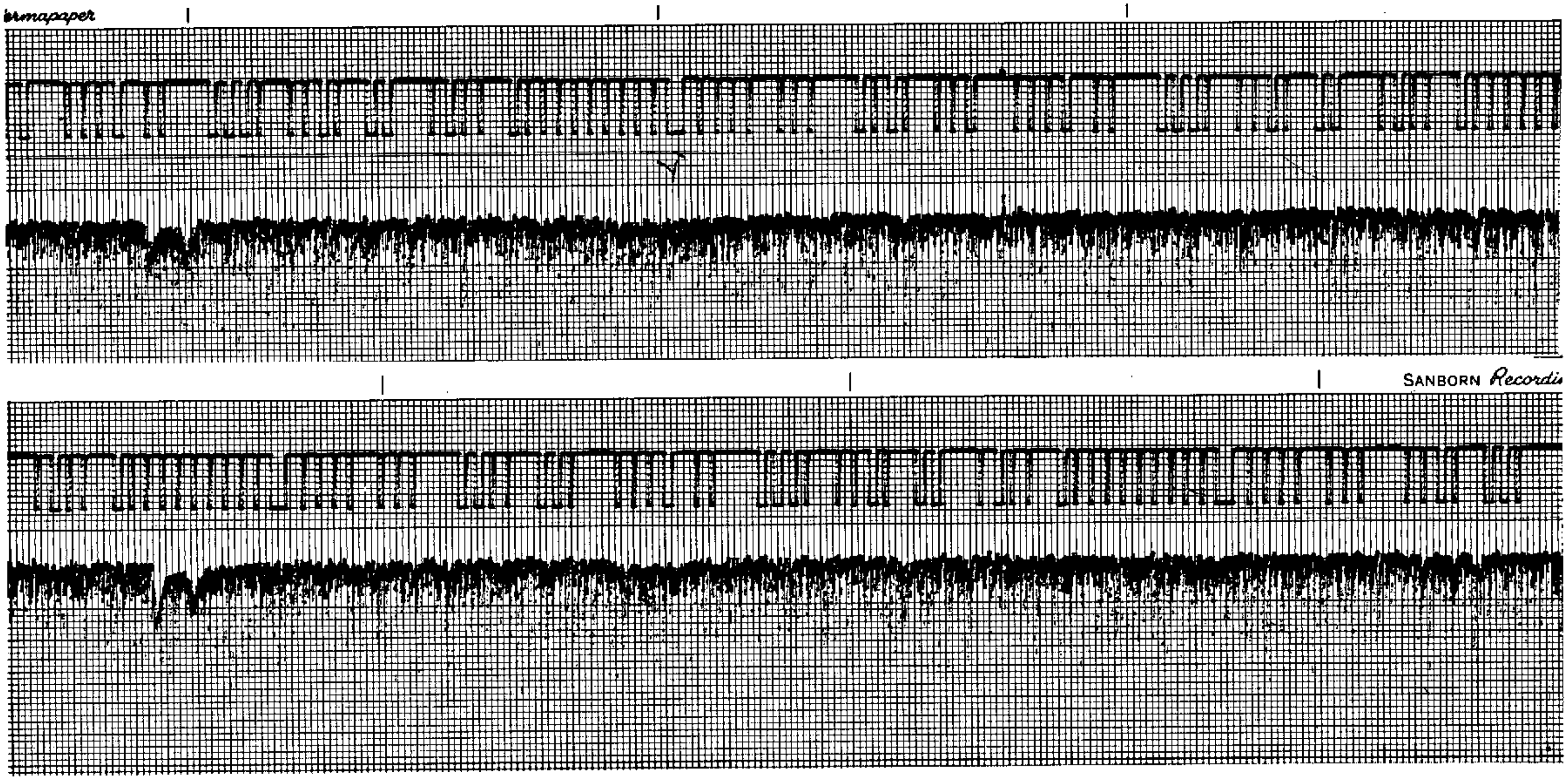
Temporal variations in the intensity of the N_2 first positive system. The numbers following UT 0545 hrs, on the time axis, are in units of seconds.


SANBORN Recording Permapaper
3159
3198
3271
3577
3755
3805
Recording Permapaper

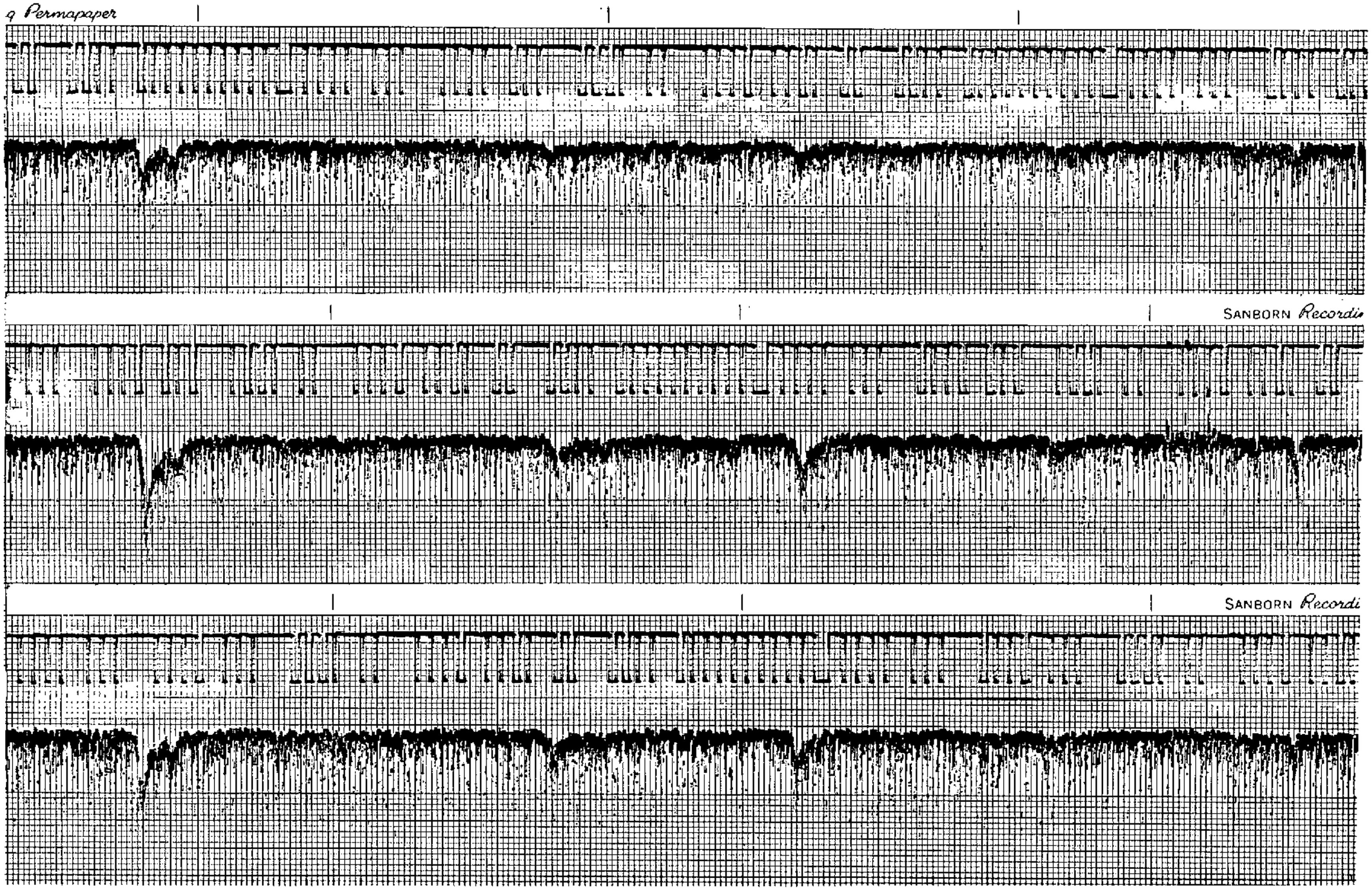


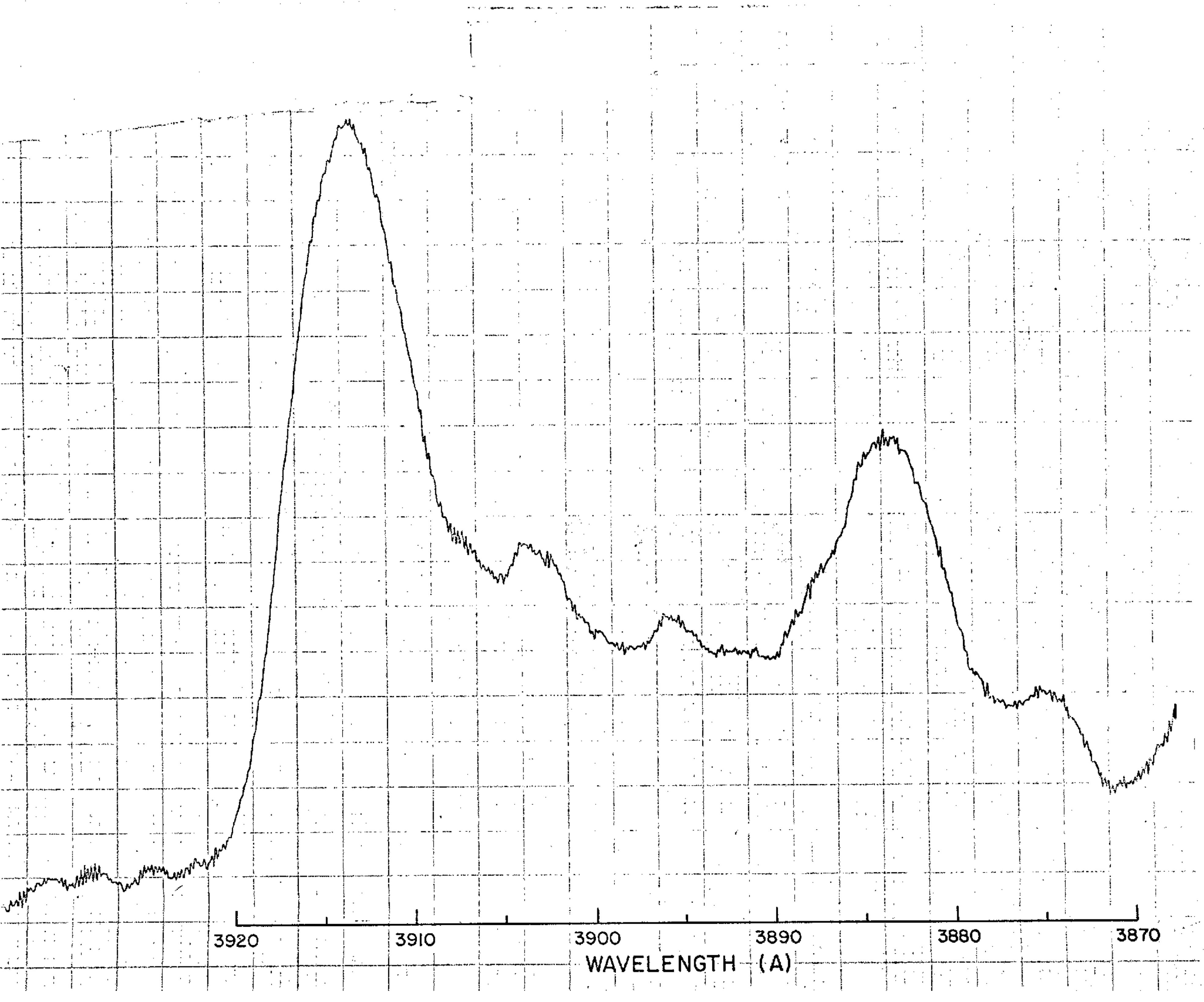
[NI]
OI [OII] [OII]
OII OII OII
OII
OI NII NII
OII OII OII
N2VK
(4-11)(1-9) (2-10) (1-10) (2-11) (0-11) (1-11) (2-12) (1-12)
N2 2PG
(3-2)(2-1)(1-0) (4-4)(3-3)(2-2)(1-1)(0-0) (3-4)(2-3)(1-2)(0-1) (3-5)(2-4) (1-3) (0-2) (2-5) (1-4)
N2+ 1NG
(3-2)(2-1)(1-10) (3-3)(2-2)(1-1)(0-0)
3000
3200
3400
3600
3800
4000
WAVELENGTH (A)

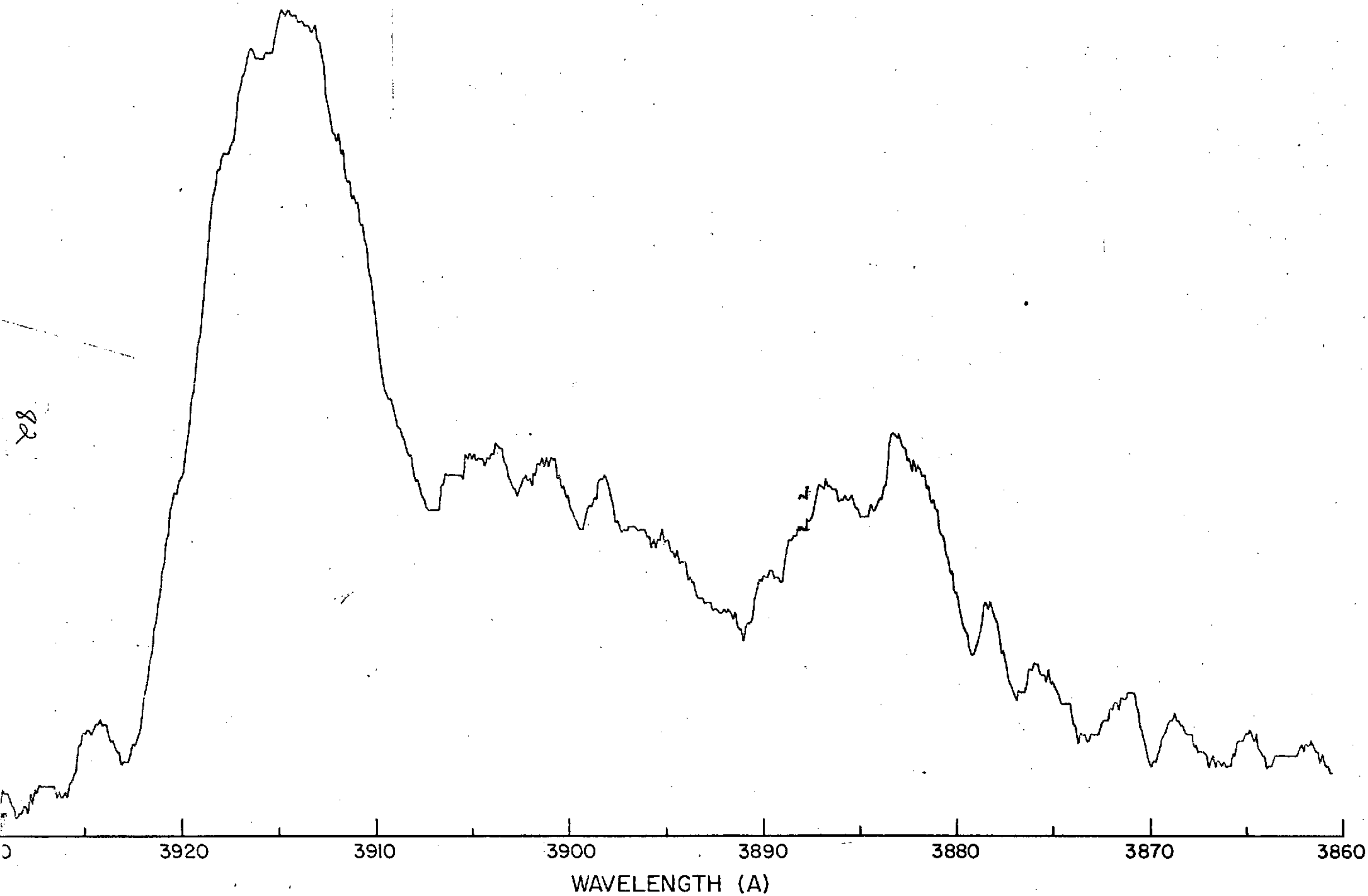
[redacted]



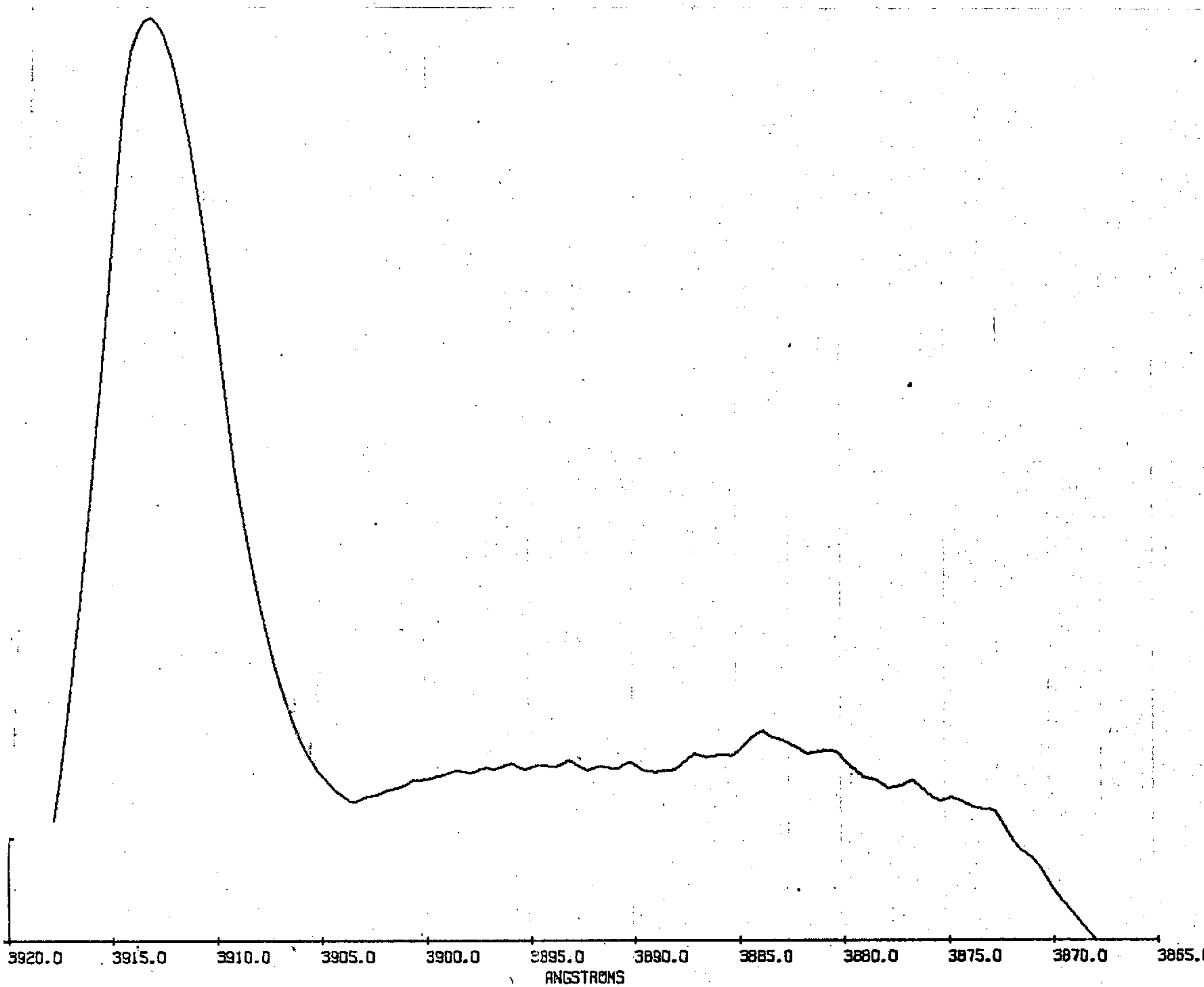
79


Permapaper
SANBORN Recordi
SANBORN Recordi

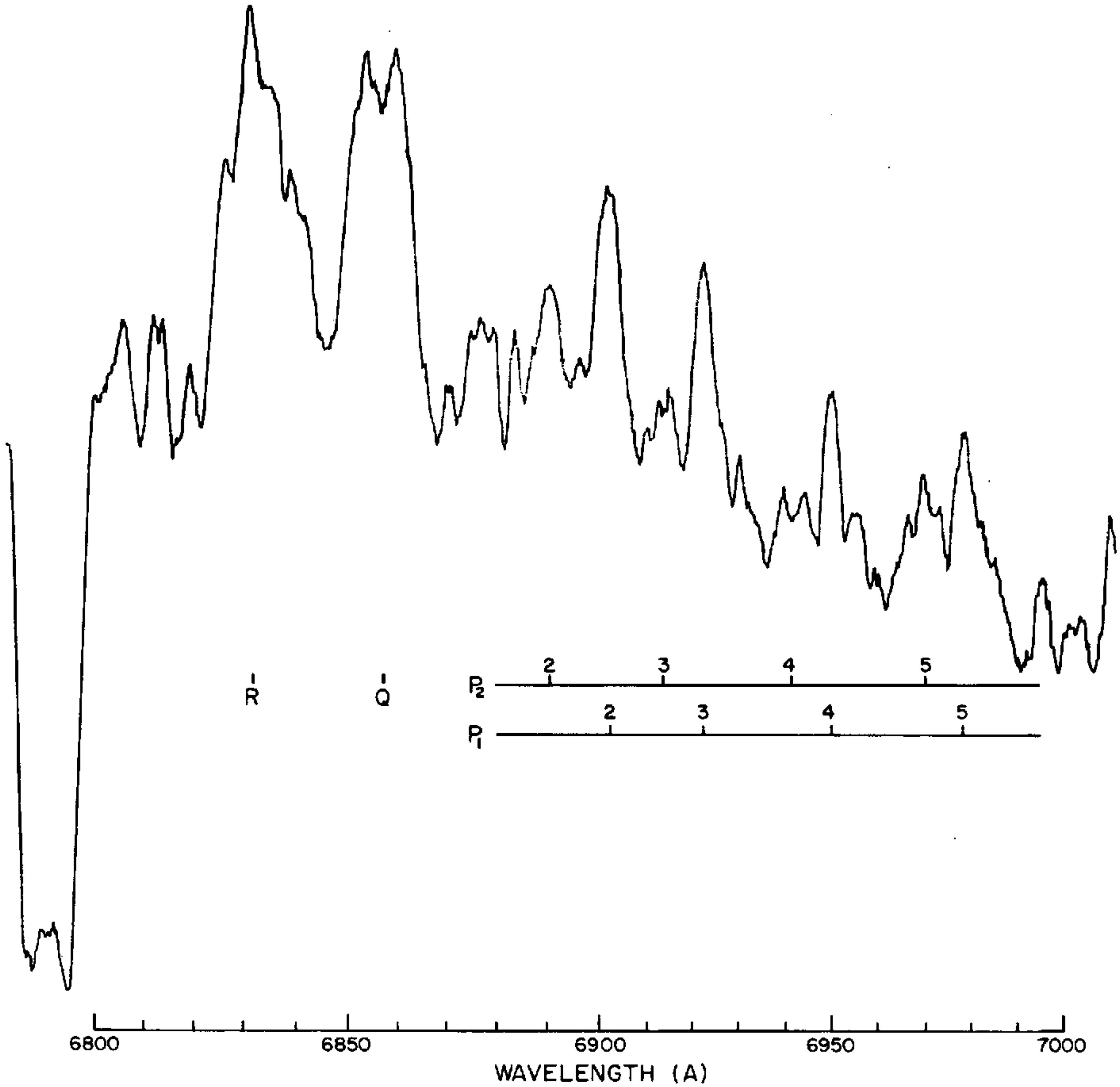

3920
3910
3900
3890
3880
3870
WAVELENGTH (A)

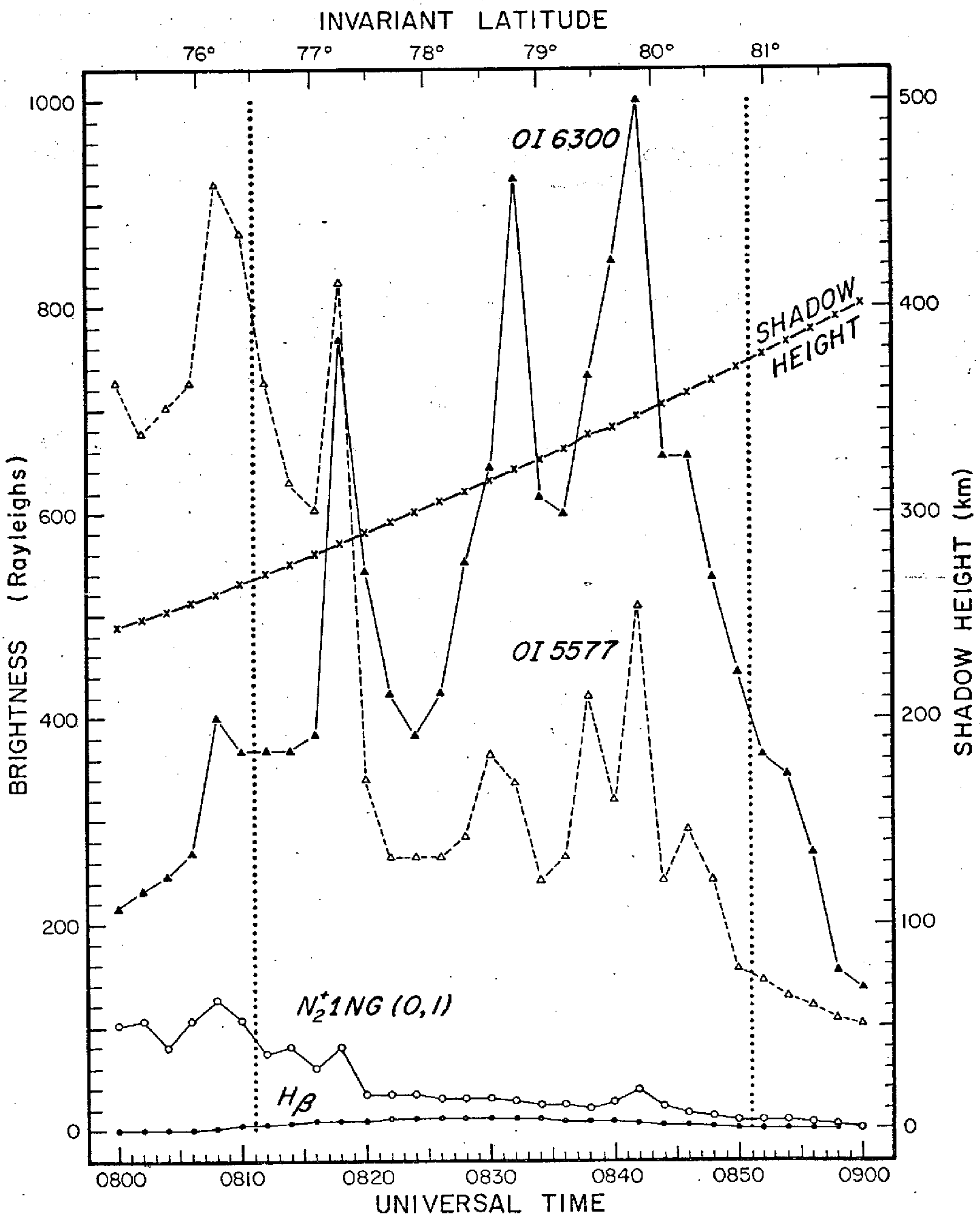


3920
3910
3900
3890
3880
3870
3860
WAVELENGTH (A)

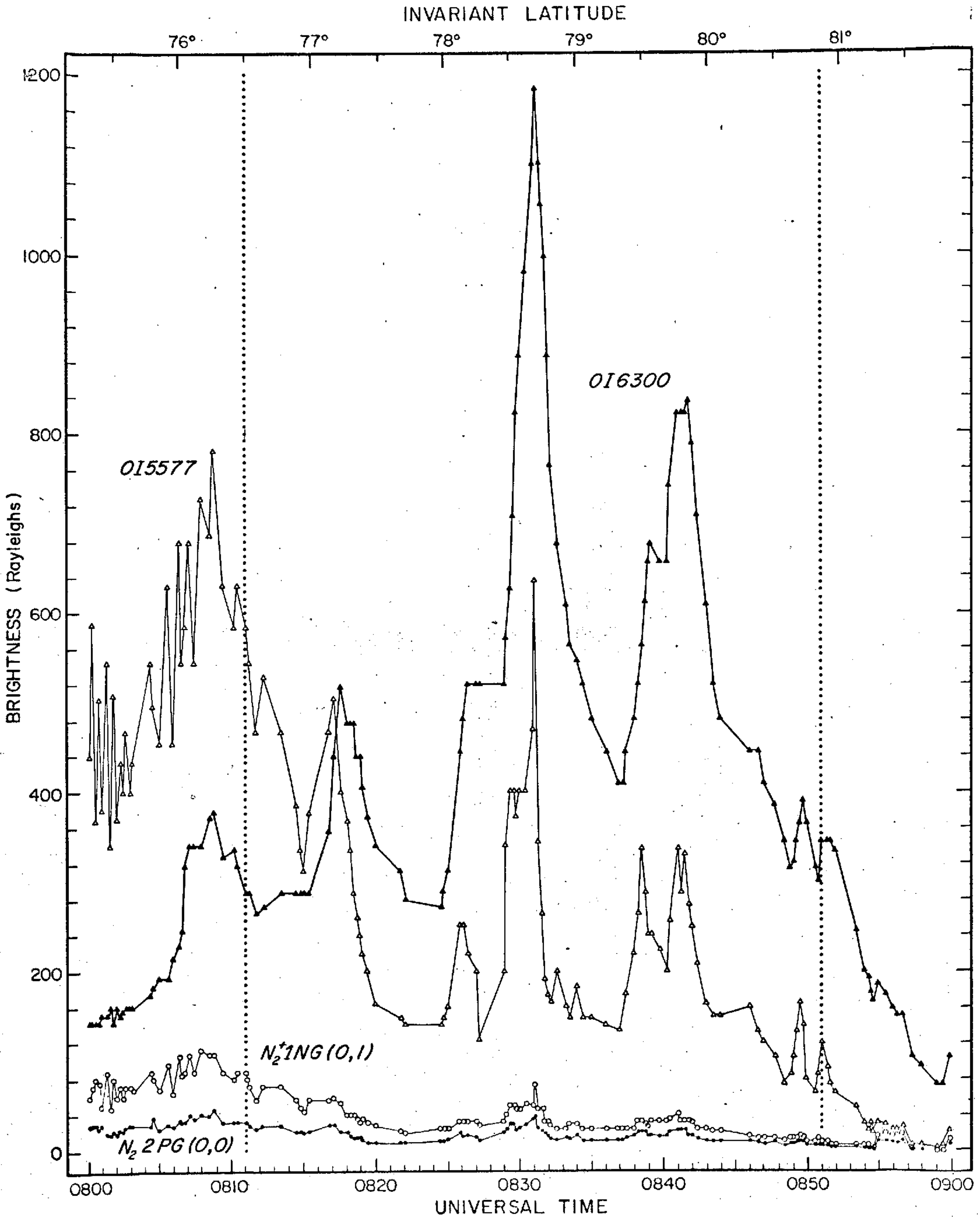


3920.0
3915.0
3910.0
3905.0
3900.0
3895.0
3890.0
3885.0
3880.0
3875.0
3870.0
3865.0
ANGSTROMS

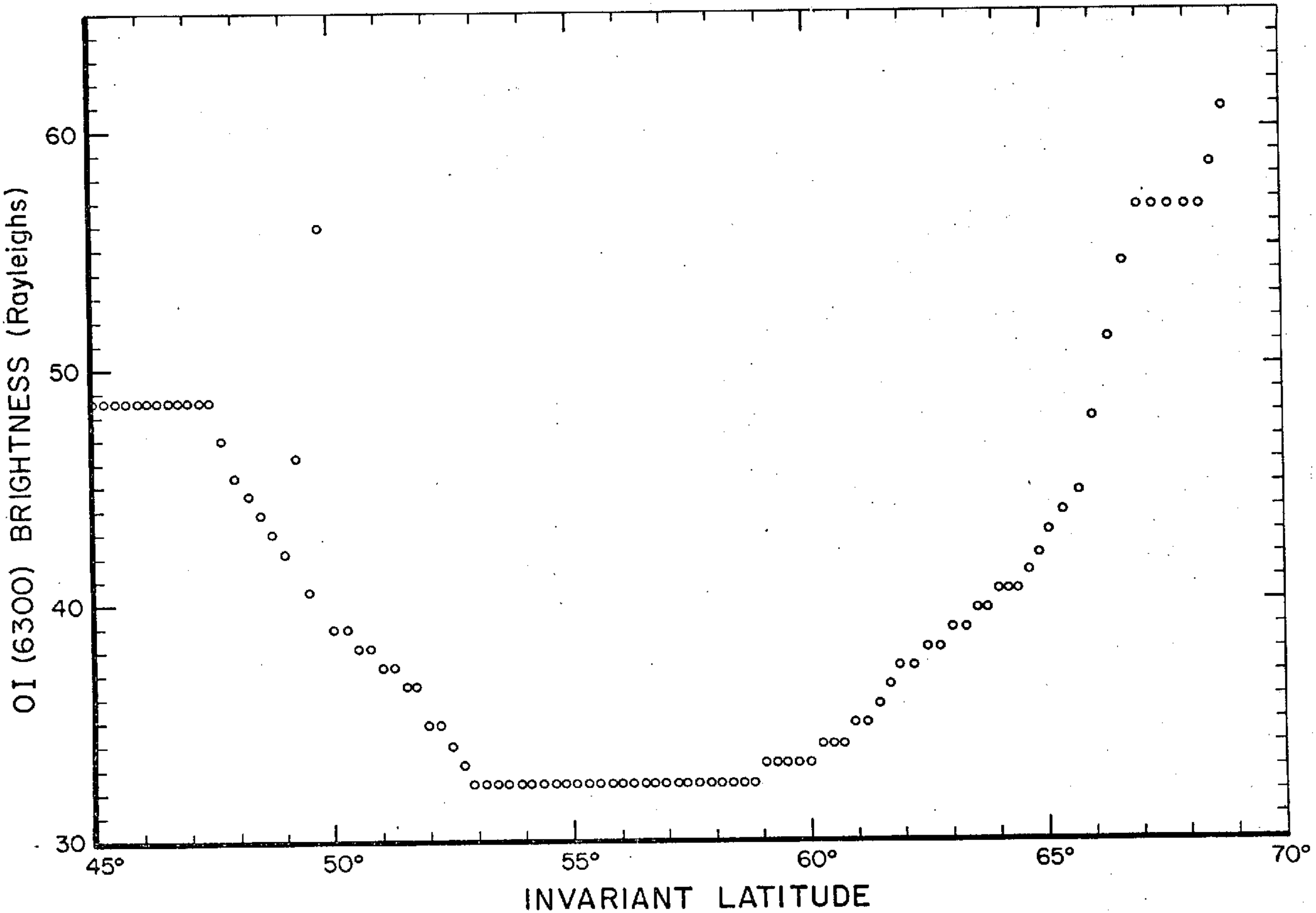

R
Q
P2
2
3
4
5
P1
2
3
4
5
6800
6850
6900
6950
7000
WAVELENGTH (A)



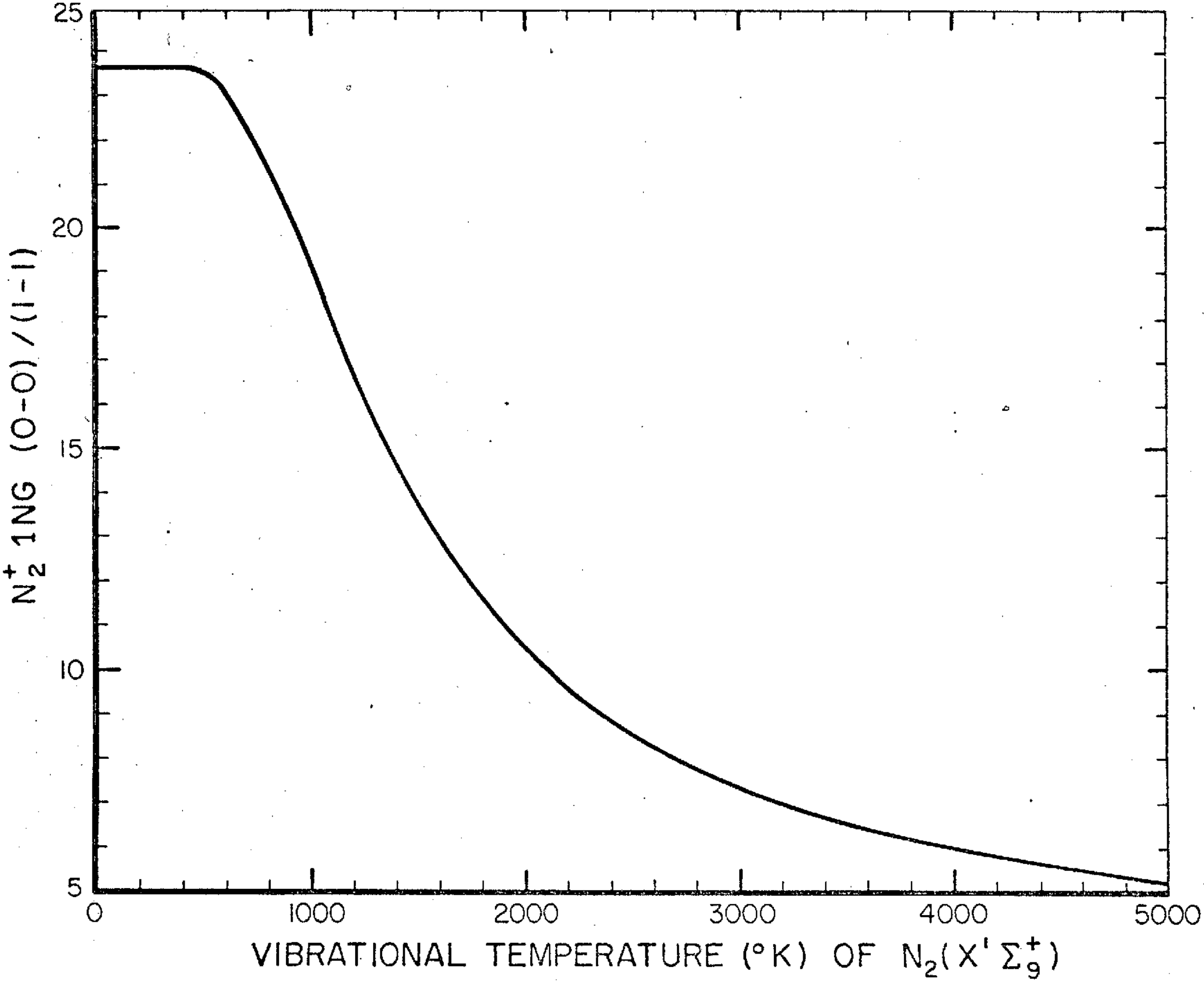
INVARIANT LATITUDE
76°
77°
78°
79°
80°
81°
1000
800
600
400
200
0
500
400
300
200
100
0
BRIGHTNESS (Rayleighs)
SHADOW HEIGHT (km)
OI 6300
OI 5577
SHADOW HEIGHT
N_2^+ 1NG (0,1)
H_β
0800
0810
0820
0830
0840
0850
0900
UNIVERSAL TIME



INVARIANT LATITUDE
76°
77°
78°
79°
80°
81°
1200
1000
800
600
400
200
0
BRIGHTNESS (Rayleighs)
OI 5577
OI 6300
N_2^+ 1NG (0,1)
N_2 2PG (0,0)
0800
0810
0820
0830
0840
0850
0900
UNIVERSAL TIME



OI (6300) BRIGHTNESS (Rayleighs)
60
50
40
30
45°
50°
55°
60°
65°
70°
INVARIANT LATITUDE



25
20
15
10
5
0
1000
2000
3000
4000
5000
N_2^+ 1NG (O-O) / (1-1)
VIBRATIONAL TEMPERATURE (°K) OF $N_2(X^1\Sigma_g^+)$

REFERENCES

1. S. I. Akasofu, Auroral Observations by the Constant Local Time Flight, Planet. Space Sci., 16, 1365 (1969).

2. S. I. Akasofu, R. H. Eather and J. N. Bradbury, The Absence of the Hydrogen Emission (Hβ) in the Westward Travelling Surge, Planet. Space Sci., 17, 1409 (1969).

3. S. I. Akasofu and F. Yashura, Red Auroras in the Morning Sector, J. Geophys. Res., 78, 3027 (1973).

4. S. I. Akasofu, Some Interesting Events Observed by the All-Sky Camera of the Geophys, Inst., Univ. of Alaska, Table II of Experimenters' Bulletin #7 (AEB-7) from NASA-Ames Res. Cent., December 1968.

5. S. I. Akasofu, NASA Flights All-Sky Camera (1969), Memo from NASA-Ames Res. Cent. to P. I., 1969 AAE, January 23, 1970.

6. J. N. Bradbury, Operation of a Three-Frequency Riometer System on the NASA 711 Aircraft during the 1968 Auroral Expedition, Lockheed Research Laboratories, January 1969.

7. J. N. Bradbury, Operation of a Three-Frequency Riometer System on the NASA-711 Aircraft during the 1969 Auroral Expedition, Lockheed Research Laboratories, June 1970.

8. K. A. Dick, G. G. Sivjee and H. M. Crosswhite, Aircraft Airglow Intensity Measurements: Variations in OH and OI (5577), Planet. Space Sci. 18, 887 (1970).

9. K. A. Dick and W. G. Fastie, A. Report on some Results from the NASA 1968 Airborne Auroral Expedition, Tech. Rept. #24, Johns Hopkins Univ., August 1970.

10. K. A. Dick, Tentative Identification of Several N_2 c $'\Sigma_u^+ \rightarrow \alpha'\Pi_g$ Bands in Auroras, J. Geophys. Res., 75, 5609 (1970).

11. K. A. Dick and G. G. Sivjee, O_2 Herzberg I Bands in the Night Airglow: Co-variation with OI (5577), J. Geophys. Res., 76, 6987 (1971).

12. K. A. Dick, G. G. Sivjee, W. G. Fastie and R. C. Schaeffer, Some Photometer Results Obtained on the NASA 1969 Airborne Auroral Expedition, Tech. Rept. #27, Johns Hopkins Univ., May 1971.

13. R. H. Eather, Photometer Data from NASA's 1968 Airborne Auroral Expedition, Rice Univ., June 1968.

14. R. H. Eather, Latitudinal Distribution of Auroral and Airglow Emissions: The "Soft" Auroral Zone, J. Geophys. Res., 74, 153 (1969).

15. R. H. Eather and Syun-I Akasofu, Characteristics of Polar Cap Auroras, J. Geophys. Res., 74, 4794 (1969).

16. R. H. Eather and S. B. Mende, Photometric Data from NASA's 1969 Airborne Auroral Expedition, Lockheed Research Laboratory, February 1971.

17. R. H. Eather and S. B. Mende, Airborne Observations of Auroral Precipitation Patterns, J. Geophys. Res., 76, 1746 (1971).

18. R. H. Eather and S. B. Mende, Systematics in Auroral Energy Spectra, J. Geophys. Res., 77, 660 (1972).

19. M. Gadsden, Progress Report on Analysis of Spectra, NOAA Aeronomy Laboratory, Colorado, 1968.

20. R. L. Gattinger and A. Vallance Jones, The Intensity Ratios of Auroral Emission Features, Ann. Geophys., 28, 91 (1972).

21. W. J. Heikkila, J. D. Winningham, R. H. Eather, and S. I. Akasofu, Auroral Emissions and Particle Precipitation in the Noon Sector, J. Geophys. Res., 77, 4100 (1972).

22. R. B. Henderson, High Latitude Airglow, M.S. Thesis, Univ. of Alaska, 1971.

23. S. B. Mende and R. H. Eather, The Spatial Entent of Auroras in O (0577) and N_2^+ (4278) Emissions, Planet. Space Sci., 19, 49 (1971).

24. S. B. Mende and R. H. Eather, Photometric Auroral Particle Measurements, in Earth's Magnetospheric Processes, Ed. B. M. Metormac, 179 (1972).

25. M. H. Rees, Airglow and Auroral Expedition Aboard the CV990 Aircraft, Final Report, Univ. of Colorado, 1973.

26. G. J. Romick, Analysis of Data Acquired on the 1968 Airborne Auroral Expedition, Geophys. Inst., Univ. of Alaska, 1971.

27. R. D. Sharp, Lockheed Coordinated Satellite Data fro the 1969 NASA CV990 Expedition, Lockheed Research Laboratories, October 1971.

28. W. E. Sharp and M. H. Rees, Latitude Distribution of Night Airglow, J. Geophys. Res., 75, 4894 (1970).

29. W. E. Sharp and M. H. Rees, Auroral Spectrum Between 1200 and 4000 Angstroms, J. Geophys. Res., 77, 1810 (1972).

30. G. G. Sivjee, K. A. Dick and P. D. Feldman, Temporal Variation in Night-time Hydoxyl Rotational Temperature, Planet. Space Sci., 20, 261 (1972).

31. U.S. Standard Atmosphere Supplements, Table of Atmospheric Parameters, 124, 1966.

32. M. H. Rees, Note on the Penetration of Energetic Electrons into the Earth's Atmosphere, Planet. Space Sci., 12, 722 (1964).

33. H. F. Bates, A. E. Belon and R. D. Hunsucker, Aurora and the Poleward Edge of the Main Ionospheric Trough, J. Geophys. Res., 78, 648 (1973).

34. E. Jamshidi, Vibrational Temperature of N_2 in the E and F Region, Master's Thesis, Wayne State Univ., 1971.

35. E. Bauer, R. Kummler and M. H. Bortner, Internal Energy Balance and Energy Transfer in the Lower Thermosphere, Appl. Optics, 10, 1861 (1971).

36. R. E. Center and G. E. Caledonia, Anharmonic Effects in the Vibrational Relaxation of Diatomic Molecules in Expanding Flows, Appl. Optics, 10, 1795 (1971).

37. E. L. Breig, M. E. Brennan and R. J. McNeal, Effect of Atomic Oxygen on the N_2 Vibrational Temperature in the Lower Thermosphere, J. Geophys. Res., 78, 1225 (1973).

38. C. G. Walker, R. S. Stolarski and A. F. Nagy, The Vibrational Temperature of Molecular Nitrogen in the Thermosphere, Ann. Geophys., 25, 831.

39. R. W. Nichols, "Laboratory Astrophysics", J. Quant. Spectrosc. Radiat. Transfer, 2, 433 (1962).

40. D. R. Bates, The Intensity Distribution in the Nitrogen Band Systems Emitted from the Earth's Upper Atmosphere, Proc. Royal Soc., Lond. A 196, 217 (1949).

41. D. R. Bates, The Emission of the Negative System of Nitrogen from the Upper Atmosphere and the Significance of the Twilight Flash in the Theory of the Ionosphere, Proc. Royal Soc., Lond., A196, 562 (1949).

42. A. L. Broadfoot, Dayglow Nitrogen Band Systems, in the Radiating Atmosphere, Ed., B. M. McCormac, 34 (1971).

43. P. D. Feldman, Daytime Ion Chemistry of N_2^+, J. Geophys. Res., 78, 2010 (1973).

44. A. Vallance Jones and D. M. Hunten, Rotational and Vibrational Intensity Distribution of the First Negative N_2^+ Bands in Sunlit Auroral Rays, Can. J. Phys. 38, 458 (1960).

45. D. M. Hunten, The Production of N_2^+ in the Atmosphere, Planet.Space Sci., 10, 37 (1963).

46. A. L. Broadfoot and D. M. Hunten, N_2^+ Emission in the Twilight, Planet. Space Sci. 14, 1303 (1966).

47. A. Dalgarno and N. B. McElroy, Twilight Effects of Solar Ionizing Radiation, Planet. Space Sci., 14, 1321 (1966).

48. E. C. Zipf, The Collisional Deactivation of Metastable Atoms and Molecules in the Upper Atmosphere, Can. J. Chem., 47, 1863 (1969).

49. R. L. Gattinger and A. Vallance Jones, N_2^+ Meinel Auroral Spectra in the 1.5μ Region, Can. J. Phys., 51, 287 (1973).

50. J. H. Moore, Jr. and J. P. Doering, Vibrational Excitation in Ion-Molecule Collisions: H^+, H_2^+, He^+, N^+, Ne^+, and Electrons on N_2, Phys. Rev., 177, 218 (1969).

51. V. Degen, A. E. Belon and G. J. Romick, The H_β/N_2^+ 4709-A Intensity Ratio and Vibrational Enhancement of N_2^+ First Negative Bands in Proton-Excited Auroras,